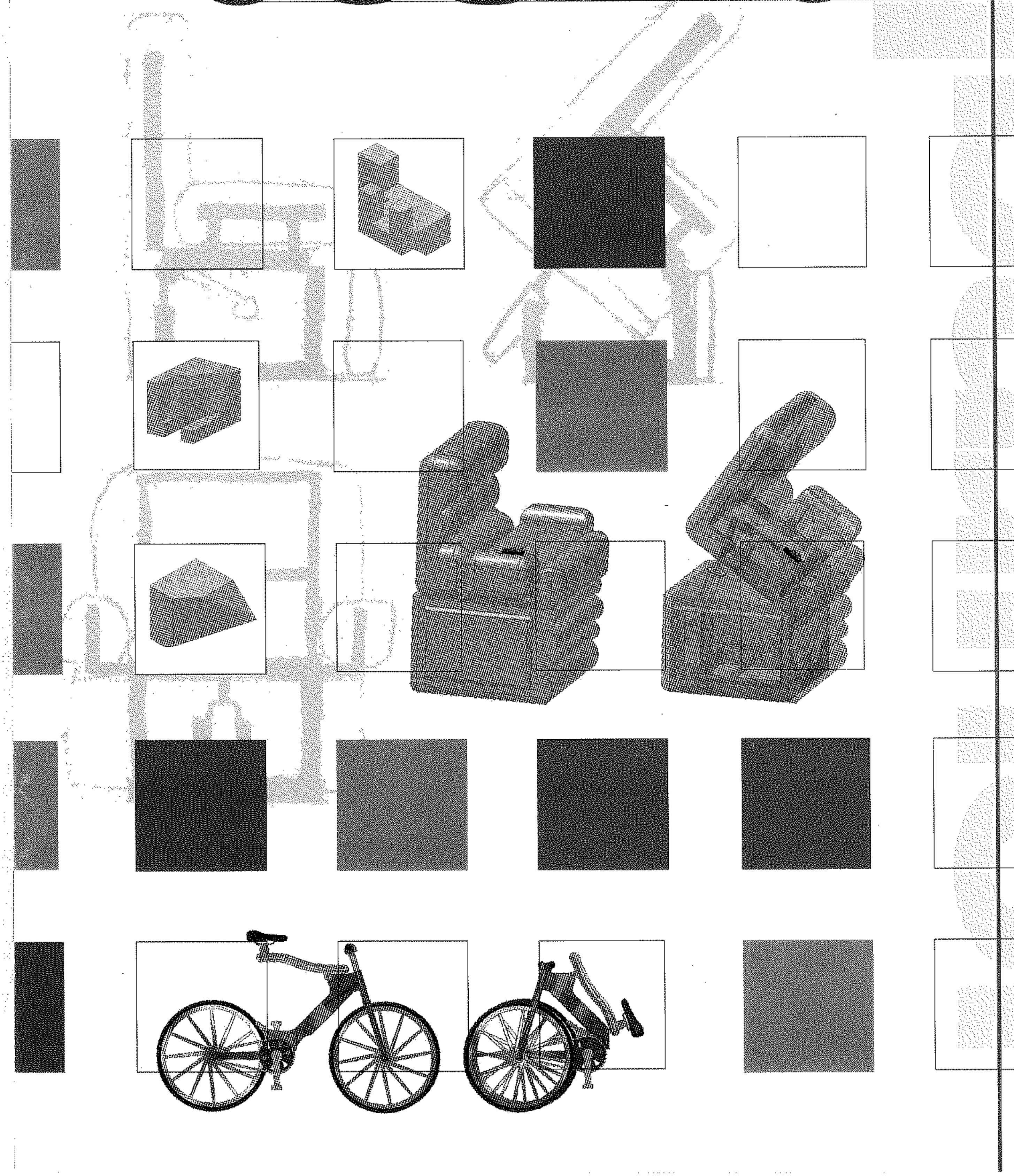
SPRING 2003

volume 67 number 2

THE ENGINEERING DESIGN GRAPHICS Journal



ENGINEERING DESIGN GRAPHICS DIVISION

ASEE

AMERICAN SOCIETY FOR ENGINEERING EDUCATION

THE ENGINEERING DESIGN GRAPHICS
Journal

SPRING 2003

volume 67 number 2

From the Editor

The Engineering Design Graphics Journal is the official publication of the Engineering Design Graphics Division of ASEE. The scope of the Journal is devoted to the advancement of engineering design graphics, computer graphics, and subjects related to engineering design graphics in an effort to 1) encourage research, development, and refinement of theory and applications of engineering design graphics for understanding and practice, 2) encourage teachers of engineering design graphics to experiment with and test appropriate teaching techniques and topics to further improve the quality and modernization of instruction and courses, and 3) stimulate the preparation of articles and papers on topics of interest to the membership. Acceptance of submitted papers will depend upon the results of a review process and upon the judgement of the editors as to the importance of the papers to the membership. Papers must be written in a style appropriate for archival purposes.

Cover graphics from Shana Smith's paper which can be found on pages 33-42.

ISSN 0046 - 2012

Dear Members:

This is hard to believe that I am finishing up my ninth and final issue of the *Journal*. It seems like yesterday I was pregnant with our third child and decided to take on this task. After three years I am ready to pass the *Journal* to Eric Wiebe and the folks at North Carolina State University.

I want to thank all the division members who have contributed to the *Journal's* success. Especially, members of the publication committee: Mary Sadowski and Judy Birchman who both served as Technical Editors, Clyde Kearns who served as the Circulation Manager, and David Kelley who served as the Advertising Manager.

I also need to thank all the authors who submitted papers to the *Journal* and the members of the review board who served during my term. Several members from the review board also helped with selecting the Editor's Award each year. During my three-year term I had the pleasure of working with three different Division Chairs. Jim Leach, Mike Stewart, and Sheryl Sorby. I can't thank them enough for all their support, answering my endless emails and sending me their Chair's message for each issue.

The best part of about being the Editor of the *Journal* was the opportunity to interact and meet so many individual involved with the success of the Division. I would like to close by saying thanks to the Division members for having the confidence to elect me to this position.

Enjoy the rest of the summer and see you at the Mid-year in Arizona!

Susan G. Miller

Susan G. Miller

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Message from the Chair

Sheryl Sorby
Michigan Technological University

Wow! It's hard to believe that a year has passed. A student once explained to me that the reason years pass so quickly as you grow older is that each year becomes a smaller fraction of your total life. When you are five, one year is 20% of your life thus far, so it seems to drag on. When you get to be my age, the fraction is much smaller, so the years go by quickly. For some of you, this must mean that the years go by at light speed.

First of all I want to thank you all for putting up with me over the past year. Lucky for me, there were lots of folks who were active and contributed to the division through their own self-motivated leadership over the past year. It really makes being division chair a breeze. So a heartfelt thanks to all of the true leaders in the division. I'm not going to try to name all of you, because I know I would leave someone out and feel terrible later on as a result. However, we should all give a big thank-you to the outgoing *Journal* Editor, Susan Miller. Being the *Journal* Editor is oftentimes thankless and Sue has done an outstanding job over the past three years. The *Journal* is like our lifeline—keeping us connected, informing us, and instructing us. Our division would be in dire straits without it, so the job of *Journal* Editor is critical to our success as an organization. Thanks also to the folks at North Carolina State who, under the leadership of Eric Weibe, will start a new era in the life of the *Journal*. Can't wait to get my first "NCSU" issue!

In reflecting about my final Chair's Message, one thing has struck me as mention-worthy. I think that EDGD is probably the first division in the history of ASEE that will have three consecutive women chairs. It should be noted that the past three *Journal* Editors for the division were also women. The times they are a-changing! When I first started in the division, I thought it seemed somewhat like a good 'ole boys network. Through the years, though, I came to recognize that this was not the case—it was really like a big family, that happened to have mostly male members. The fact that we have had several women in leadership positions in recent years, speaks volumes about the openness that the EDGD members feel towards new ideas and perspectives. We truly are a forward-thinking group.

As one of the oldest divisions within ASEE, we could sit back and rest on our laurels, but we continue to move forward and break new ground. Perhaps this is due to the nature of the subject that we teach. (I think it's safe to say that graphics instruction has changed much more significantly over the past 50 years than has instruction in thermodynamics.) Perhaps it's due to inherent personality traits in individuals who are willing to spend a career in graphics instruction. For whatever reason, the EDGD exemplifies excellence in undergraduate education. I have never interacted with a group of professionals so willing to try something new in the classroom. Graphics educators are often pushing the boundaries and continuously looking to move the discipline forward. Kudos to all of you for keeping the profession alive and well.

Once again, thanks for allowing me to be division chair over the past year. It has been my pleasure to serve. I'm sure Judy will do a great job, as will Holly after her. Keep those papers coming! We love to hear from you.

Oppenheimer Endowment Fund

Dear EDGD Members:

The Engineering Design Graphics Division of ASEE is establishing an endowment fund for the Oppenheimer Paper Award, which is given each year to the author/presenter of the Best Paper at the annual EDG Midyear meeting. Frank Oppenheimer created the award to improve paper presentations at the EDG Midyear meeting, and he has personally sustained it financially over the last three decades. The purpose of the endowment is to permanently honor him and his contribution to the EDG Division by having a fund to support his award in perpetuity.

Individual EDG member donations are being solicited over the next several months until a target corpus is met. Several donations and pledges in the range of $50-$250 have already been received. If you would like to donate, write your check made out to "ASEE EDG Division," write a note for "Oppenheimer Endowment," and send it to:

Ronald E. Barr
Chair, Oppenheimer Endowment Fund Committee
Mechanical Engineering Department
Mail Code C2200
University of Texas at Austin
Austin, Texas 78712

Schroff Graduate Student and New Faculty Participation Grant

announcement

Dear EDGD Members:

The Schroff Graduate Student and New Faculty Participation Grant is being offered again this year. This grant provides a maximum of $500 each for new faculty who are still in their first two years of teaching but are not current members of the Division and graduate students to attend the EDGD Midyear Meeting in Scottsdale, Arizona from November 16-18, 2003.

The Schroff Graduate Student and New Faculty Participation Grant is intended as a developmental program to encourage potential graphics instructors and new faculty members to participate in the activities of the Engineering Design Graphics Division (EDGD) of ASEE. It is also anticipated that the grant recipients will make the EDGD one of their professional affiliations and activities on an ongoing basis throughout their professional career.

The grant is provided by Schroff Development Corporation and must be used to pay for travel, accommodations, and/or conference registration. The grant is open to all graduate students in graphics-related programs (for example, Engineering Graphics, Technical Graphics, and Computer Graphics). Application forms and guidelines for the grant are available on the EDGD Web site at http://www.east.asu.edu/edgj/edgd/awards/awards.html.

The schedule for the application and selection process is:

October 1:	Deadline for applications submitted to the Selection Committee
October 15:	Selection Committee notifies potential grant recipients
October 29:	Deadline for notice of commitment of recipients submitted to Selection Committee
November 5:	Grant checks sent to recipients

Details about the Schroff Graduate Student and New Faculty Participation Grant are available on the EDGD Web site at http://www.east.asu.edu/edgj/edgd/awards/awards.html.

Judy Birchman

Building the Foundation for a PLM Centered Engineering Graphics Curriculum

David S. Kelley and Craig L. Miller
Purdue University

Abstract

With curriculum areas in Animation, Computer-Aided Design (CAD), Construction Graphics, and Multimedia, the Department of Computer Graphics Technology at Purdue University is known for its excellence in the application of technologies associated with computer graphics. This paper describes curriculum development efforts within the CAD area of study. The Computer-Aided Design area's mission is to produce individuals that can apply computer graphics technologies to mechanical design and manufacturing processes. Its curriculum is focused on the utilization of graphical based applications within manufacturing and engineering processes. Topics covered within this paper include departmental background information, the CAD area's core knowledge base, curriculum enhancements, and the development of a minor in CAD.

Introduction

Engineering design graphics has been a recognized course since the beginnings of formal educational programs in engineering and technology. While this discipline has evolved considerably since the advent of computer-aided design (CAD), its place as a recognized course within bachelor degree granting universities appears to be at a crossroad.

Drafting Technology as a degree granting program is available at most community and technical colleges. While the history of such programs has placed an emphasis on drafting standards and practices, the dominance of CAD within engineering and architectural environments has caused these programs to migrate toward an emphasis on CAD, sometimes at the expense of drafting. While the worth of drafting instruction can be debated, the growing power and capabilities of CAD have lead to four-year degree programs. Table 1 reveals a partial list of such programs.

Most of the listed programs have similar curriculums to what can be found in traditional two-year drafting technology programs; added room in each curriculum allows for a more in-depth study into drafting fields (such as architecture or mechanical design) and into CAD technologies. One exception on the list is the Computer-Aided Design Technology program at Eastern Michigan University (2002). While this program does have traditional graphics oriented courses (e.g. Engineering Graphics, Industrial Drawing, Machine Design, etc.), it is also strong in programming to include CAD development and customization. Lacking in each curriculum is competencies in Product Data Management (PDM) integration and Product Lifecycle Management (PLM). More specifically, attention is not being given to the

CAD Related Programs

University	Program Title
Western Washington	Industrial Graphics
Eastern Michigan	Computer-Aided Design Technology
Appalachian State	Industrial Drafting and Design Tech.
Central Missouri	Computer-Aided Design and Drafting
Southeast Missouri	Technical Graphics
East Carolina	Design

Table 1 *Institutions with CAD related Programs (National Association of Industrial Technology, 2002)*

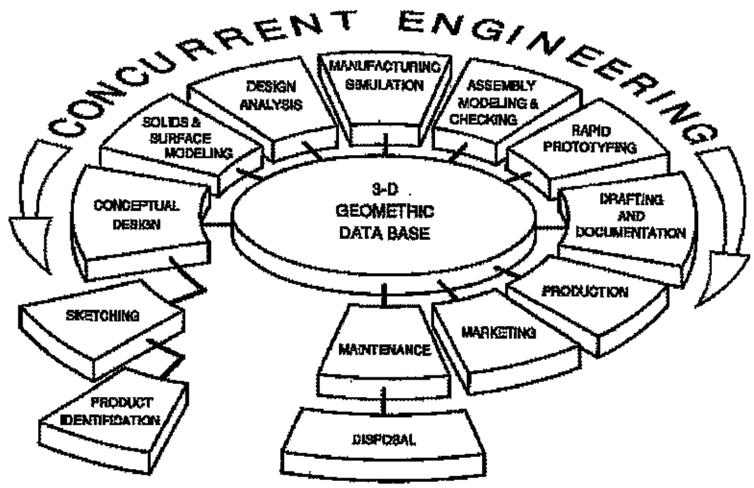

Figure 1 *Concurrent Engineering and CAD (Barr & Juricic, 1996)*

management of CAD data across extended enterprises.

Leading forces behind many engineering graphics curriculum models are derived from philosophies of concurrent engineering. Concurrent engineering was established to help meet the quality demands of functions within the lifecycle of a product. Within conventional design processes, functionality is followed by manufacturing, then assembly, then serviceability (Bedworth, Henderson, & Wolfe, 1991). Each concern is tackled consequently with minimum information flow occurring between parties. "Concurrent engineering has as its purpose to detail the design while simultaneously developing production capability, field-support capability, and quality" (p 141). It involves the concurrent arrangement of design functions into one design team consisting of individuals that represent the life of a product (from concept to scrap). Combined with information technologies, concurrent engineering teams have the capability to communicate from anywhere in the world. This technological enhancement promotes the removal of communication barriers that commonly exist when design departments and production facilities are geographically dispersed.

The integration of components of a digital enterprise, as represented by Barr and Juricic's model in Figure 1, represents a concurrent approach to design processes with CAD data as the common denominator. The importance of this model is reflected in popular engineering graphics textbooks such as Bertoline and Wiebe (2002) and Lockhart and Johnson (1999) and in the approaches to engineering graphics instruction that reflect concurrent engineering practices (Barr & Juricic, 1997; Kelley, 2001; Newcomer, McKell, Raudebaugh, & Kelley, 2001). Commonly absent in engineering graphics education is an in-depth study into the management of CAD data. While CAD system capabilities continue to grow, instruction in the utilization and configuration of product data management applications, especially enterprise wide systems such as Dassault Systemes' ENOVIA and Parametric Technology Corporation's WindChill, cannot be overlooked. Robert Cumberland conducted an in-depth study into the PDM needs of progressive manufacturing organizations (Cumberland, 2000). His study attempted to determine if engineering graphics curricula based on philosophies of concurrent engineering are valid for engineers and technologists. His study was composed of a questionnaire that targeted leaders in manufacturing and design enterprises (n = 40). Validating the concurrent engineering model, his project indicated that there is a strong demand for skills in the management of design data across extended enterprises.

Department Background

The Department of Computer Graphics Technology (CGT) at Purdue University is integrating PLM and concurrent engineering philosophies and technologies into its curriculum to meet the data management needs of extended enterprises. The CGT Department is an entity that applies computer graphics technologies to industries as diverse as construction, manufacturing, entertainment, animation, multimedia, Internet, and computer-aided design. Within the department there are four areas of specialization: Computer-Aided Design, Construction Graphics Communication, Interactive Multimedia Development, and Animation. The department's mission is "to prepare practitioners, managers, and leaders in computer graphics, accelerate technology transfer to business and industry, and develop innovations in the applications of computer graphics" (2002). While the department is diverse and sometimes focused in its application of computer graphics, its graduates do have a broad understanding of graphics concepts. The Computer-Aided Design (CAD) area places its graphics emphasis on the application of computers and computer graphics to the solving of manufacturing problems. Its curriculum is targeted at the application of computer-aided design systems to the solving of manufacturing and design problems, while also providing a strong background in other graphics areas (raster and vector imaging, animation, & html).

Core Knowledge Base

The CAD design area set out in 2000 to establish a curriculum that meets the needs of manufacturing and engineering enterprises in the 21st century. The following is the area's adopted mission statement:

It is the mission of the Computer-Aided Design area of the Department of Computer Graphics Technology to produce individuals that can apply computer graphics technologies to the mechanical design and manufacturing process.

The curriculum model utilized in this process was a top-down approach that required the identification of a core knowledge base. The purpose of this base was to provide a foundation for the deriving of mid-level competences that in turn could be utilized to drive course curriculums. The following is a listing of the established knowledge base:

- *Design Communication:* The ability to analyze the intent of a design and to communicate this intent to others. The ability to take abstract design concepts and communicate them to others.
- *Visual Conceptualization:* The ability to conceptualize visually the design of a product. The ability to take abstract design concepts and portray them visually.
- *Manufacturing Graphics Integration:* The ability to understand, synthesis, and integrate manufacturing related computer graphics fundamentals throughout the digital enterprise. The ability to apply graphics fundamentals to the solving of manufacturing problems.
- *Design Process Management:* The ability to manage the design process to include data, attributes, and individuals related to the lifecycle of a product. The ability to improve design and manufacturing processes through the use of graphics and visualization techniques.
- *PDM Integration:* The ability to integrate and enhance design processes, concepts, and procedures through the use of graphics and product data management approaches.
- The ability to understand and evaluate the affects that technology has on society. The ability to apply technology in a manner that promotes the well-being of all individuals. The utilization of ethnical reasoning and decision making when applying technological devices.

Course Curriculum Enhancements

As previously stated, the purpose for identifying a core knowledge base was to find a foundation from which course curriculums could be derived. A review of the curriculum revealed two significant midlevel competencies that were missing: CAD programming and product lifecycle management.

All CAD systems come available with some form of application programming interface (API) or customization toolkit. Systems such as AutoCAD are known for their relatively easy customization interfaces, while other systems, such as Pro/ENGINEER, have rigorous and unintuitive toolkits. An identified midlevel competency missing in the CAD area of specialization was the customization and programming of graphics applications. While there was consideration for a course in CAD customization with AutoCAD as the primary application, it was decided to take a less focused approach with graphics programming as the preferred offering. With CAD customization toolkits being diverse and usually dissimilar, a strong background in programming languages and graphics programming was deemed appropriate and more suitable. During the curriculum evaluation efforts, it was noted that all students within the department, despite area of specialization, were required to take one course in Visual Basic and one course in Visual C++. On top of this, two courses in graphics programming were developed. The first course covers basic graphics programming with an emphasis on OpenGL and computer graphics mathematics. The second course covers application development, interactive programming, DirectX, the ACIS CAD kernel, and AutoLisp programming.

Another identified competency missing in the CAD curriculum centered on the philosophy of product lifecycle management (PLM). A major concern with large original equipment manufactures (OEMs) is the ability to share design data with first and second tier suppliers. According to Brunnemeier and Martin, in the automobile industry, CAD interoperability has been estimated to cost over $1 billion per year (1999). To increase competitiveness, OEMs are requiring first and sub-tier companies to interface with their design data. This requirement is increasing the awareness of product lifecycle management applications within the design processes of companies. This emerging technological challenge in industry has promoted an awareness of data communications and PDM applications within the CGT's CAD curriculum. The first PDM application integrated into the curriculum was Pro/INTRALINK, which is now the standard CAD data management tool in two courses: CGT 226 – Constraint-Based Modeling and CGT 426 – Industrial Applications for Simulation. In addition, a third course in Product Lifecycle Management is currently in the curriculum approval process. This course mirrors a newly approved graduate course on the same topic.

Under the umbrella of PLM, an area of interest that was deemed desirable in the curriculum is computer-networking fundamentals. A review of recent job placements will find that many of the graduates of the CAD curriculum go to work for smaller sub-tier companies. These individuals have to serve as CAD technologists and PDM administrators. Within this latter role, knowledge of networking and data communications is essential. Based on this need, an identified topic in the CAD curriculum is a practical course in networking technologies. An impediment to integrating this need is a lack of laboratory facilities and instructional support. Coordination efforts are currently in the works with the Information Technology faculty at Purdue University to find a suitable course for CGT students.

CAD Minor

Because of the continued demand for students with expertise in CAD and computer graphics related manufacturing applications, many of the courses within the CAD area of specialization have been increasing in popularity among engineering and engineering technology students. To address this growth, the CAD faculty set about during the Fall 2000 semester to develop a minor within the Department of Computer Graphics Technology.

Minors at Purdue have to be accepted by the degree granting department before students can complete its requirements and have it denoted on their transcripts. To manage enrollment and to facilitate student progress, the minor was offered to a select number of departments. Programs selected from the Schools of Engineering include Aeronautical & Astronautical Engineering (AAE), Mechanical Engineering, Agricultural & Biological Engineering, Interdisciplinary Engineering, and Industrial Engineering, while programs from the School of Technology include Computer-Integrated Manufacturing Technology (CIMT), Industrial Technology, and Mechanical Engineering Technology. Outside the School of Technology and the Schools of Engineering, students from the Industrial Design and Industrial Management programs can also pursue the minor. Most students in the minor come from the AAE and CIMT programs.

The curriculum offerings come from courses offered in the CAD area of specialization; there are no courses offered exclusively for students in the minor. The primary prerequisite for entry into the minor is one course in basic engineering graphics. Other prerequisites include one course in computer programming, one course in physics, and college algebra. Purdue requires a minimum of 12 semester hours in any minor. Within the CAD minor, students can select from the following courses:

- CGT 226 – Constraint-Based Modeling
- CGT 323 – Surface Modeling
- CGT 326 – Product Lifecycle Management
- CGT 423 – Manufacturing Documentation Production and Management
- CGT 426 – Industrial Applications for Simulation

Conclusions

Technologies associated with design processes are revolutionizing the way that computer-aided design systems are deployed in design and manufacturing environments. The concept of product lifecycle management and the applications associated with PLM are facilitating CAD data exchange and decreasing the time-to-market for products. The CAD area of specialization within the Department of Computer Graphics Technology is in the process of redesigning its curriculum to incorporate PLM principles and advance computer graphics technologies. The logic behind the area's curriculum develop efforts places an emphasis on the utilization of CAD data and CAD systems within the design cycles of products. As in the past, students in the program receive extensive training on CAD systems, but they also must develop an understanding of how CAD fits into the entire lifecycle of a product. Within this understanding, students receive an appreciation for data communication technologies and how to integrate CAD applications into more complex systems.

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Teaching Geometry through Dynamic Modeling in Introductory Engineering Graphics

Eric N. Wiebe, Ted J. Branoff, and Nathan W. Hartman
North Carolina State University

Abstract

This paper is part of an ongoing set of papers by Wiebe, Branoff, and Hartman looking at how constraint-based 3D modeling can be used as a vehicle for rethinking instructional approaches to engineering design graphics. In particular is the goal of moving from a mode of instruction based on the crafting by students and assessment by instructors of static 2D drawings and 3D models. This approach to instruction results in overemphasis on correct size and style of geometric elements (e.g., the 'look' of the graphic), rather than on the underlying problem-solving process used to create the model. Instead, an approach based on dynamic modeling is proposed. This approach provides the opportunities for students to learn about geometry through the embedding of geometric behaviors into models and then testing these behaviors via dynamic change of the model. This approach is better aligned with larger goals of better problem-solving abilities in the technology and engineering workforce. Example instructional activities are presented.

Introduction

While 3D constraint-based modeling has been in use in industry for more than ten years, it has only been within the last few years that there has been widespread adoption of these modeling tools at colleges and universities. 3D modeling tools have been identified as a key component of some areas of engineering education for a while (e.g., Barr & Juricic, 1992), but it has only been recently that educators have begun to investigate how the newer constraint-based modeling tools bring a new set of possibilities to instruction (e.g., Ault, 1997). Even more recently, researchers have looked more holistically at how these constraint-based tools can be effectively integrated into a modern engineering graphics curriculum (Baxter, 2001; Branoff, Hartman, & Wiebe, 2002; Cumberland & Miller, 2001). In looking at the curricular implications of these tools, it becomes important to identify what are the core concepts and abilities we intend for students to gain from an introductory course in engineering graphics.

The knowledge and abilities gained have to be relevant both in the short term for further courses they will be taking in school and in the long term as life-long learners and productive workers in industry (Connolly, 1999). A particular challenge is to strike a balance between narrowly defined competencies with particular software tools and larger 'big picture' conceptual knowledge about what drives this whole class of constraint-based modeling tools. Wiebe (1999a, 1999c) has previously outlined the similarities in the underlying functionality between the most popular constraint-based tools and their relatively accessible user interfaces. This trend continues to this day and has largely removed the need to focus large portions of an engineering graphics course to training on specific software packages in order to meet industry needs. Working under this assumption, this article will instead focus on one of the key conceptual areas of modeling that should be emphasized in any modern engineering graphics curriculum: geometry. That is, a primary instructional goal should be the development of students' understanding of Euclidean and topological properties of planar and solid geometry using constraint-based 3D modeling tools, not skills training for specific software tools.

Applied geometry has been part of engineering design graphics since its inception. Being applied, however, means that how it is integrated into the curriculum becomes dependent on what tools are being employed and what the perceived needs are for the students in their future education and employment. The introduction of constraint-based modeling into the curriculum means that, once again, there needs to be extensive discussion of how geometry should be applied in this evolving curriculum (Wiebe, 1999b). This paper will outline how applied geometry can be integrated into a modern engineering graphics curriculum. This will include the use of geometric relations within a 3D solid model representing a virtual, engineered product. Of particular interest is the definition of the size and location of a 'feature' in a solid model relative to its constituent features or a frame of reference. These goals are addressed within a framework of a student identifying key geometric features within the virtual product and how this geometry needs to be controlled in order for the model to be of maximum usefulness in the product development process.

Dynamic Modeling

Engineering graphics has, in many ways, struggled with the same issues that technology education has over the past 40 years. That is, how to move beyond teaching 'craft' with the end all and be all goal of creating a 'product', to teaching 'process', where how you get to the finished stage is more important than the product itself (McCormick, Murphy, & Harrison, 1993). In other words, the final product and its precursor stages become artifacts that represent the problem-solving process of an applied geometric problem. While a certain level of technical competency with the tools (3D constraint-based modeling tools in this case) is critical in solving the problem, problems need to be designed where critical geometric thinking is also required to arrive at an acceptable solution. It is, however, a challenge to come up with modeling problems where a 'good solution' can be assessed by measures other than geometric accuracy (Clark & Scales, 2001). Historically, engineering graphics artifacts turned in as part of coursework are assessed by visual inspection. This could mean reading dimensions on a multiview drawing or it could be judging the length, angle, or higher order geometric relations of model elements. The latter, when done with normal views of planar geometry, can often be done with a fairly high degree of accuracy. However, judging these geometric relations in pictorial views can be prone to error (Wiebe & Converse, 1996).

Another alternative is electronic measuring of geometry within the computer model. However, this still does not necessarily get past an assessment of the model solely based on the final artifact. An alternative to visual inspection of hard copy printouts or passive inspection on the computer monitor is active probing of the actual computer model. While complete inspection of how the entire model has been constructed and constrained can be very time consuming, focused probing of key features is more effective. Often this probing takes the form of changes of key dimensional values, revealing how the underlying construction of the model responds to these changes. This use of 'dynamic modeling' shows promise as a strategy when the goal of assessment goes beyond geometric accuracy of the final model (Branoff et al., 2002). An interesting variation on the instructor probing the model with dimensional constraint changes is to require the student to produce multiple versions of the model based on instructions provided by the instructor. Here, the challenge will be to design modeling problems that visually reveal the design intent embedded in the model via readily identifiable visual artifacts.

Dynamic models as a strategic instructional goal addresses a number of key issues. First, it allows for a broader assessment of the modeling problem that encompasses both 'solution' and 'accuracy'. The modeling design process that leads to the solution is embedded in the model by the way the student chooses to construct their model. These construction decisions are revealed to the instructor through dynamic modeling manipulations. Second, these dynamic modeling activities address the important issue of having instructional activities reflect authentic professional practice. In this case, dynamic modeling can come in the form of 'engineering change orders'. The worth of a model now is based not on a single geometric form, but how well it can be iterated through a number of configurations as it moves through the simulated engineering design process. Students now experience the complete cycle of model definition, comparison to design goals, and modification based on needed changes. The ease of making these geometric modifications are a primary driving force for industry to adopt these constraint-based modeling tools, however, many companies will readily admit that their engineers and designers are often ill-equipped to build robust models that truly capture the geometric design constraints (Wiebe, Norton, Summey, & Howe, 1997).

Successful solutions to modeling problems should hinge on addressing three key elements. First, the solution will depend on correct initial geometry; this is usually as far as most assignments go. Second, it will depend on embedding the correct behaviors via geometric constraint definition. Third, it will depend on correct translation of the initial design constraints and engineering change orders into geometric definitions. This approach, however, is not without challenges. First, can a taxonomy be developed that identifies the core geometric behaviors that all students should master? Second, given the inherently open-ended nature of most design problems, can a robust enough set of activities be developed that allows for assessment within a practical amount of time and with a high degree of reliability? That is, can modeling problems be designed that have students incorporate these behaviors in a systematic and controlled fashion. The remainder of the paper will address this first challenge while indirectly pointing to solutions to the second.

Embedding Geometric Behavior

As mentioned previously, there is a high degree of uniformity of interfaces and modeling tools across the most popular constraint-based modelers used in instructional settings (Wiebe, 1999a). This uniformity allows for the definition of a generic model creation process that is applicable in a wide range of instructional settings. This modeling process is outlined in detail in Bertoline & Wiebe (2002) and will be used as a basis for the discussion here. Also of note, that while the complete virtual product definition most always involves the creation of assemblies, instructional constraints usually limit an introductory course to focusing on single part modeling. Still, all part modeling should be done in the context of knowing that these parts will eventually be part of a larger assembly.

A core part of geometry definition takes place in the sketcher where 2D profiles are defined on a planar surface. These sketches can be defined relative to existing geometry in the model or to other sketch elements. In instruction, emphasis should be made on the fact that two fundamental types of geometric constraints are being placed on the profile. First, explicit constraints in the form of dimensional constraints are defined. These constraints are not static dimensions, but control size or location of a particular geometric element. As such, new values can be assigned to the constraint and a new configuration of the profile (and model) can be evaluated based on other constraints in place. Second, implicit constraints are often applied to the profile based on implied geometric relations between elements in the profile or profile elements and existing geometry. These are fundamental geometric relations such as parallelism, colinearity, same size, etc. These implicit constraints are often applied automatically and not readily apparent to the student. Activities that require students to evaluate the effect of these constraints and/or modify them helps to make them more salient.

Further geometric constraints are applied by the creation of a feature from the sketch profile. The type of Boolean operation applied to the swept profile and the side of the profile sketch loop to apply the operation on is at the heart of any modeling activity. The choice of modeling operation should be part of a larger strategy of how the final geometry is created and what geometric features will need modification for future operations. The sketch plane on which the profile sketch was created also constrains the feature through its orientation and location. Similarly, the direction, transformation type (linear versus revolute), and distance of the sweep also provide geometric constraints that can be used to alter model geometry.

Instruction on these geometric constraint tools should not just focus on the tool (e.g., '...here is how you constrain profile edges parallel.'), but also on the end design goals of the part. The starting point should be: What is the functionality of the assembly? Where does this part reside in relation to other parts in the assembly?. And how might this part need to change (geometrically) in the future? From there, a rationale is developed for why the geometry is shaped as it is and how it should be constructed and constrained to provide for certain geometric behaviors under dynamic change. More advanced activities can include behavior definition across parts in an assembly and definition of behaviors via explicit mathematical equations.

Behavior Types

All model behavior is ultimately based on how the model is constructed. That is, it is based both on the geometry of the model and on how this geometry is constrained relative to other geometry or to itself. Behavior reveals itself through how the model changes form when one or more of its constraints is modified. For example, if the length of a bar is doubled in length, then how the holes in the bar change (or don't change) position is based on the behavior embedded in the model. Model behavior is central to all dynamic modeling activities and correct behavior should be explicitly defined by the modeling problem. It follows that correct (and incorrect) model behavior should be clearly identifiable by the student and the instructor assessing the modeling problem. Which behaviors are central to an introductory engineering graphics course should be identified and integrated in modeling activities.

These behaviors appropriate to an introductory course might be called 'basic behaviors'. Most all of these basic behaviors will be based on a single constraint modification that impacts one or two dimensional constraints or geometric relations. Advance behaviors -- those that are based on multiple modifications, impact multiple constraints, or involve equation-driven constraints -- are most likely going to be confined to an advanced course.

Changes in a model based on behavior definition can result in two fundamental changes in the model: geometric or topological (Zeid, 1991). Geometric change, as defined here, means change in the size or shape of a geometric feature. Topological change involves the deletion or creation of vertices, edges or faces. This typically implies the whole or partial deletion of previously defined features. The distinction between these two types of changes is important since geometric relations may be defined via other geometry. The deletion of existing geometry can cause previously defined relations to fail -- a common occurrence when engaged in extensive dynamic modeling.

Basic behaviors based on geometric relational constraints that students should be exposed to in an introductory course include:

- Parallelism
- perpendicularity
- horizontal and vertical (based on a global coordinate system)
- symmetry
- same size
- colinearity
- tangency
- alignment/fixing to an existing entity

Dimensional constraints that control behavior students should have experience with include:

- horizontal, vertical, angular, and aligned control of linear location
- size of linear elements
- circular/angular size of radial elements
- location of reference geometry
    - internal to sketch
    - external to existing geometry

In order to assure uniformity in behavior of the model, models should be fully constrained. That is, the geometry and topology of the model should be fully defined via a combination of dimensional and geometric relational constraints. Allowing geometry to 'float' gives way to the potential for unpredictable behavior, impacting the ease in which the dynamic modeling assignment can be assessed. Unexpected behavior, in fact, should be a flag to the student and instructor that the student has not fully thought through how this model is to behave and how to properly constrain it so that it exhibits these behaviors under the prescribed conditions. The flip side of this is that modeling problems need to be designed so that they readily reveal common problems with embedding behavior via constraints.

Examples

The following are some example modeling problems that could be used in an introductory engineering graphics course. These examples apply the basic geometric behaviors described above to single part models and demonstrate how dynamic modeling techniques can visually reveal their underlying behavior to students.

Symmetry

Symmetry as a behavior can be explored using a two-feature model of a plate with a hole in it See Figure 1). An initial plate can be created with a hole in its center, but how the hole behaves under modification can depend on whether the hole was meant to always be centered or offset a fixed distance from one edge of the plate. Here, with a model like this, topological change to the plate where an offset dimensional constraint is attached can be explored. Also, reference planes can be used as a constraining element. If the plate is a midplane extrusion from a reference plane, then the plate can expand symmetrically about a fixed hole. A more advanced exercise can show how equations can control the location of the hole. In Figure 1 (a), the initial object is shown as a plate 100 X 40 X 10 mm with a 20mm hole through the center. Examples (b) and (c) show two possible results when the plate size is changed to 70 X 50 mm. In example (b) the hole is located 50mm from the left end and 20mm from the back, so the hole does not remained centered when the overall width and depths are modified. In example (c), plate and the hole are centered on the origin of the part, therefore, changes in the width and depth dimensions keep the hole centered on the plate.

This plate can be put in the context of an assembly with the hole aligning with either a stud or fastener and the faces at either end of the 100 mm dimension needing to align with mating faces. Changes to the assembly can be specified as part of a problem that has either Figure 1(b) or 1(c) exhibiting the correct geometric behavior.

Tangency

In a sketch profile, whenever a profile has more than one element and at least one of them is a curved element, a decision has to be made concerning tangency. Whether or not a curve is tangent to a straight or curved element may not be readily visible in a static model, but carefully designed dynamic changes can readily reveal a tangent constraint or lack

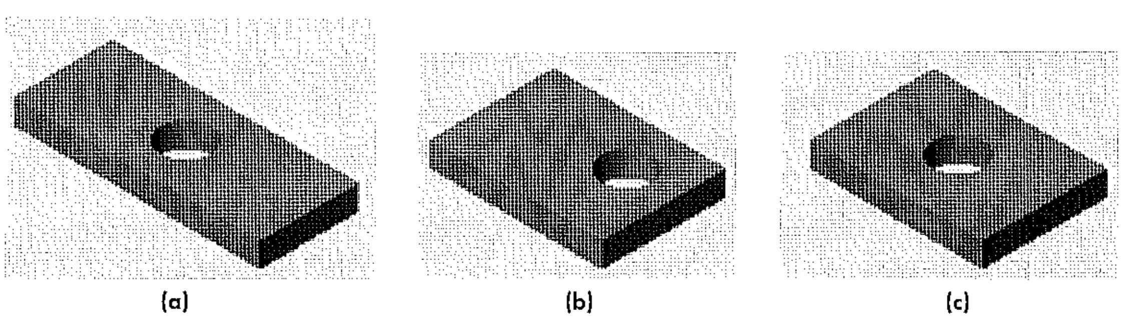
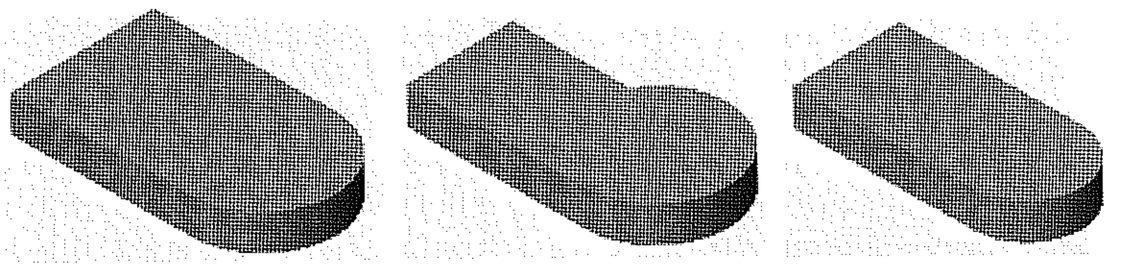


Figure 1 *Symmetry*



(a) (b) (c)

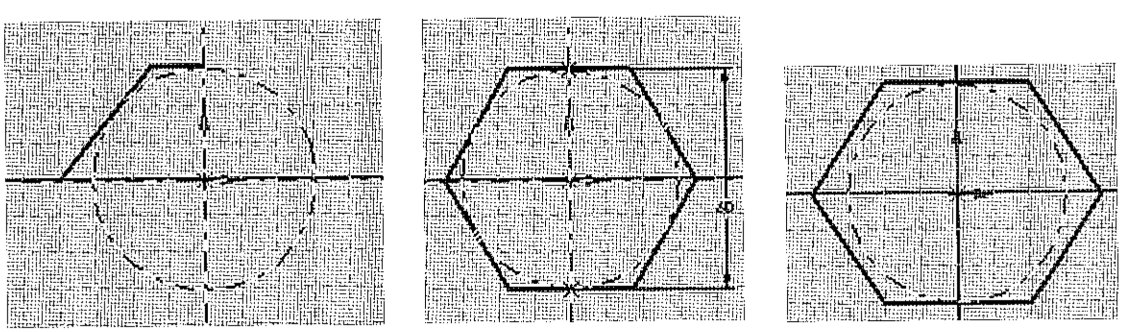
Figure 2 *Tangency*

thereof. Problems can be designed to demonstrate how the number of location dimensional constraints needed to fully constrain a curved element changes with the number tangency geometric relational constraints in place. In Figure 2 (a), the front and back surfaces of the object are intended to be tangent to the curved surface. Example (b) illustrates what might happen if a tangency constraint is not present when the depth of the part is changed from 40mm to 30mm. Example (c) represents an object with two tangent constraints.

An alternative problem would be to put the plate in an assembly where the radius of the curved element needs to be preserved regardless of the depth of the part. Since most modelers will put in implicit geometric constraints of tangency when the part is initially constructed as seen in Figure 2(a), creating the proper behavior will require explicitly removing the tangency constraint on one or both sides of the curved element in the sketch.

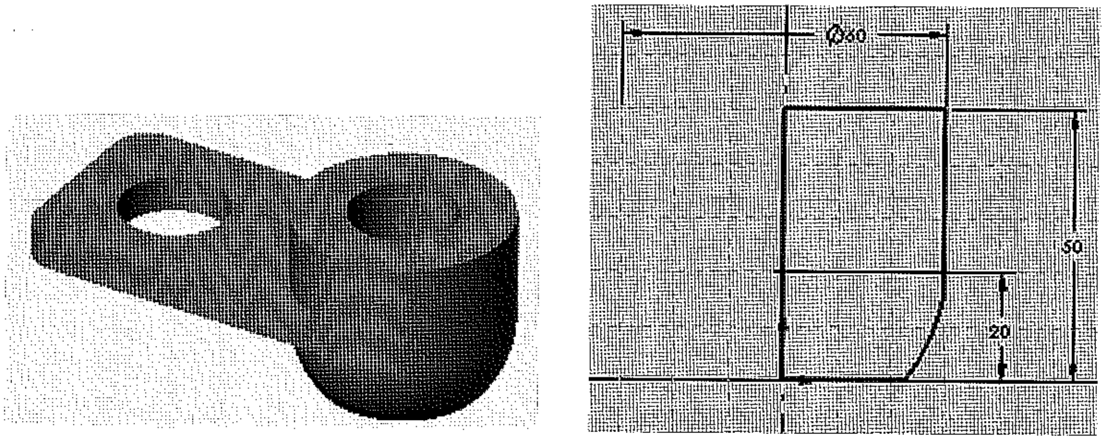
Regular Polygons

Creation of a regular polygon from scratch in a profile provides an opportunity to explore symmetry, similar length, and similar angle constraints. Exercises can be designed that explore the differing solutions (e.g., that vary the number of dimensional constraints versus the number of geometric relations) to fully constrain the polygon. Also, the types and number of constraints needed to fully constrain the geometry can vary based on the number of sides and can also vary based on behaviors the polygon needs to exhibit under modification. Figure 3 (a) illustrates starting with a construction circle and two centerlines and 1 1/2 sides of the hexagon. After adding tangent constraints between the circle and the two profile lines, the lines are mirrored about the centerlines and the necessary constraints are added to fully define the polygon as shown in example (b). Another approach, shown in example (c), is to require only a construction circle and ask the students to determine the number of constraints required to fully define the polygon (regular or otherwise). This activity provides an introduction



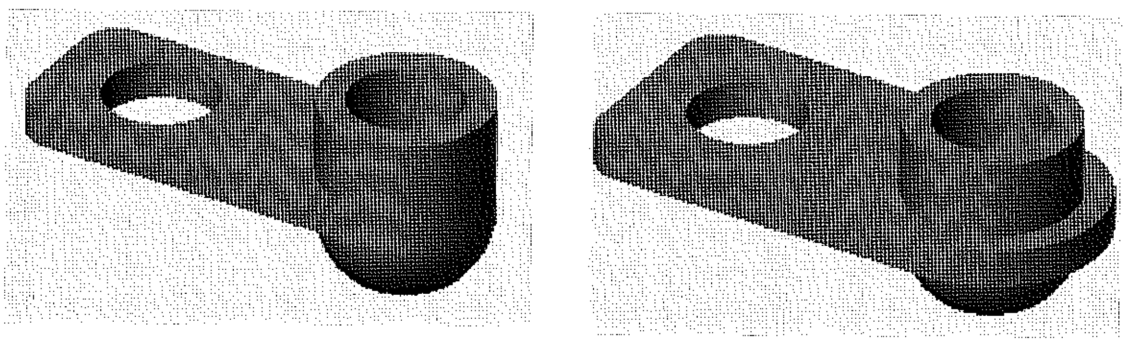
(a) (b) (c)

Figure 3 *Regular Polygons*



(a) (b)

Figure 4 *Driving 3D Geometry with 2D Sketches*



(a) (b)

Figure 5 *Modifying the Model and Breaking Constraints*

to construction geometry other than sketch planes and the role it plays in structuring final geometry.

The regular polygon exercise can be done with the polygon being swept out to form one feature of a multi-feature part (e.g., a bolt), and/or having the part in the context of a larger assembly. An assembly could be designed requiring a hexagonal feature that was not based on a regular hexagon. In this case, a student would need to more selectively establish a combinations of equal size, equal angle, or symmetry constraints. Additional challenge can be added by requiring the hexagonal shape to driven by dimensional constraints located on specific faces.

Driving 3D Geometry with 2D Sketches

Another powerful exercise for students is one where they are required to use 2D sketch data to drive 3D features. Figure 4 shows an object where the depth of the part is driven by the 60mm diameter dimension for the cylinder. Figure 5 (a) illustrates what happens when the diameter is changed to 45mm if the correct tangent constraints are present between the horizontal plate and the cylinder. Figure 5 (b) shows the same modification when the student is required to break the tangent constraint. As with the tangency example above, the spherical surface can be made tangent to the cylinder or not, depending on how the design requirements are specified.

Conclusion

A modern engineering graphics curriculum needs to move beyond the crafting of static models and drawings derived from such models. To do so, one needs to begin with a clear taxonomy of geometric behaviors derived from dimensional and relational constraints applied to the model. Problem-solving oriented modeling assignments that demand dynamic manipulation of the models provides a vehicle for revealing model behaviors to the students and the instructors assessing the student work. Assessment based on dynamic modeling assignments provides the opportunity to judge the quality of the model problem solution, both on the modeling process and the end product.

Increasingly, industrial use of constraint-based modelers depends on the creation of sophisticated virtual products that represent multiple geometric configurations of current products and the embedding of geometric behaviors that represent engineering design constraints (Courter, 1999; PTC, 2000; Versprille, 2001). 'Smart' models that reflect critical design constraints allow for rapid creation of new versions of the product and saves companies considerable time and money. Increasingly, employers will demand graduating students who are able to create these sophisticated models. For students learning modeling in this dynamic, problem-based environment, there will be the added benefit of being able to experience engineering design from the standpoint of geometric problem-solving. This will provide an essential counterpoint to classes engineering students already take where much of the problem-solving is numerically based.

These changes in the engineering graphics curriculum need to be implemented in such a way that they not create undue burden on instructors, otherwise, they simply will not be adopted. Dynamic modeling problems that allow reliable assessment through visual inspection of different iterations of a model or simple probing of the electronic model are indeed possible. All of the examples given above demonstrate behaviors that are clearly visible in pictorial views of the model, either in printouts or on the screen. The key will be to tightly define the design problem and what constitutes 'correct behavior'. Careful selection of models, geometric definitions, and required modifications will all result in a quality instructional experience.

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A Delphi Study of Assessment Practices in Engineering Education

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Abstract

During the early fall of 2001, a study was conducted that looked at assessment areas and practices in the field of engineering/technical graphics education. The study focused on the particular assessment practices that should be used in grading introductory courses in engineering/technical graphics. A panel of 12 experts was selected, which included members from high school, community college, and university systems from across the United States. These experts, using a modified three round Delphi method, worked together to reach consensus on a grading matrix for use in introductory level courses. Outcomes from this study include a listing of major assessment categories with content objectives that experts felt should be addressed in the assessment process. A model for assessment (taxonomy) is presented as a conclusion.

Introduction

Over the past fifty years, a new revolution has taken place in the engineering/technical graphics profession. We have seen major changes in both the pedagogical practices we use in the classroom and the foundational information we teach our students. With the advent of the computer and other related technologies, we have seen a major shift in content taught in introductory and advanced classes as well as the diversity of offerings most of us are now responsible for (i.e. animation, web publication, CAM). However, given all of the changes within the past half century, little inquiry has been made into the way professional educators in our field assess the content we teach and the impact technology has had on the profession's foundational core areas. Considering these important issues, the authors of this study decided to continue a thematic research project looking into assessment, changing foundational content, and how evaluation can be related to a taxonomy for assessing student work.

Many educators in the field of education consider a discipline of study to have a taxonomy for learning and assessment that can be directly tied to its content and the pedagogy used in the classroom. Considering this, and the changes in our profession, the lack of a taxonomy in our field needs to be addressed at the national level. For the past three years, the researchers of this study have worked towards generating content for developing future educators for our field, the content to be taught in our undergraduate courses, and the processes and procedures for assessing student achievement. This study is yet another part of the inquiry into these areas. The researchers wanted to determine the basic core competencies that students need to exhibit and that should be assessed in introductory courses in engineering/technical graphics. For this step of the thematic research, a modified Delphi technique was selected in order to reach consensus among experts in our field. Representation of all levels of education was used to makeup the expert panel from which consensus was drawn. This included high school through the university level, since these core competencies affect all students, whether in high school or pursuing a degree at a university. Once these core competencies were identified, a model for evaluation, in the form of a taxonomy to evaluate outcomes, was developed to start the profession's quest for describing the knowledge gains students have in learning to visualize in our classes. At the end of this study, a proposed model for visual literacy is suggested as a basis for assessing the content students are learning and the areas of visualization they should acquire from our discipline.

Evaluation of Course Offering

A definition of evaluation, as related to curricula areas and taxonomies, was provided by Phi Delta Kappa in 1970. This definition stated that "educational evaluation is the process of delineating, obtaining, and providing useful information for judging decision alternatives" (Phi Delta Kappa, 1970, p. 60). The tasks of evaluation are to "provide continuous readings along the congruence and contingency dimensions, to identify options, to explicate values and criteria, and to provide information that weighs the options in relationship to the criteria" (1970, p. 59). In 1991, Thomas (1991) provided a more inclusive definition of evaluation by stating that assessment is "the use of various methods to gather both quantitative and qualitative information at the level of program, institution, and/or system, to describe and sometimes to make judgments about the inputs, resources, and/or outcomes" (p. 1). This definition incorporated the use of gathering information to make judgments about course quality, and the recent shift towards accountability with the emphasis on effectiveness of assessment. Performance criteria to be assessed is one phase of defining and evaluating a program or course offering. In a study, conducted by Diez and Moon (1992), they stated that there are two areas for assessment criteria. The first included determining measures for satisfactory performance. The second was to assess the quality of a course. This study based its content on areas related to Purposed-Based Assessment. Purposed-Based Assessment is used to find the following basic purposes for conducting an assessment: to define the optimal performance that should take place; to determine the actual performance of students; to describe the feeling of key stakeholders (i.e. the Delphi Process); to identify the problem areas of a program; and to select or prioritize effective solutions to the problems within a program (Hirumi, 1993).

Elements of Evaluation Models or Taxonomies for Assessment

Evaluation models used in education have been defined and classified by professional educators in different ways. Most scientific research conducted in education classifies models as simplified representations of a process or system. Models used in education go beyond this definition of the term by implying that a model represents reality, often in a simplified way, and provides structure and order to a process or system (i.e. rubric). Models are used to help visualize something that cannot be directly observed (Bagdonis & Salisbury, 1994). The value of evaluation models has been seen in the assessment models used in education. Stufflebeam used the input-process-product model to understand complex dimensions of a context that surrounds an intervention and the interpretation of its effects. Kaufman stresses the need for careful analysis during the assessment process so that changes can be planned and problems resolved. Kirkpatrick gives attention to reactions of learning behavior, including attitudes, values, and perceptions. Overall, models are valuable to educators because they promote an in-depth analysis of the evaluation process used in education rather than limiting or constraining the evaluation process (Altschuld, 1995). Karr (1994) concluded, in an article on collaborative assessment, that to develop a plan for authentic assessment of an educational program or course one must examine how it can be conducted. This leads to the identification of characteristics and criteria needed in an assessment model if "true" assessment is to take place. Bagdonis and Salisbury (1994) stated that models (taxonomies) can be developed through general characteristics contained in assessment processes, but literature is lacking to identify a way to validate an assessment model. Expert opinion can be used to validate assessment models (i.e. the Delphi method), but such opinion needs to be followed by a formative evaluation technique.

Bagdonis and Salisbury (1994) studied other research in the field of educational assessment and identified criteria for general model development that should be used for assessment purposes. One process identified was the steps or strategies for developing models. The steps include: divide the problem into simpler problems, develop objectives and a purpose for the model, seek analogies, specify an element within the problem and follow it through, and record the obvious input and output relationships. Another outline for developing a model includes the following steps: (a) identify the problem; (b) define a model to serve as a reference, its strategy; (c) investigate the current system being assessed; (d) analyze current problems; (e) draft a working model that is compatible to the current situation, dedicated to the reference model; (f) evaluate and revise the new model based on the opinion of experts and the results found through the assessment process.

Another author in the field of assessment model development who studied other professionals in educational assessment gave the following criteria for model development. A model: (a) needs to be a replica of some type; (b) is an agreed-upon symbol; (c) provides a habitual process for evaluating and conceptualizing a program; (d) provides a shortcut in the conceptualization process; (e) can be complete or not incomplete in form; (f) can be easy and simple, or difficult and complex, depends upon the users; (g) must provide standardization and control of processes and conceptualizations; (h) is the means, not the beginning or end of an assessment process. As indicated in this review of literature, some type of symbolic visual representation needs to be included in an assessment (taxonomy) model for better conceptualization of the evaluation process. Also, a hierarchical structure needs to be included for assessing different levels of subject understanding and proficiency (Blankenbaker, & Miller, 1987).

The Delphi Method

The Delphi technique used in this study started as part of Air Force sponsored projects with the RAND Corporation in the early 1950's, and related studies used as early as 1948. This project, known as Project Delphi, had as its objective the development of a reliable method of reaching a consensus of opinion among a group of experts. Its original justification was to access accurate information that was normally unavailable or too expensive to obtain. This justification is still valid for Delphi studies (Sackman, 1975, p. 11). Since the Delphi process was successful in dealing with these issues, it was utilized in other fields as a way of using the consensus of experts to assess information or provide solutions to problems.

The Delphi technique has been used for educational applications for the past two decades. According to Volk (1990), by 1986, approximately 441 dissertations had employed the Delphi technique and most of these were in the field of education. Panel members for Delphi studies in education typically are experts from the field being studied. Lewy (1977) stated that in curriculum development, "expert judgments are needed as input data by the curriculum decision makers. Many competencies must be integrated to produce a new curriculum; no one person would possess all the expertise required" (p. 167).

The Delphi has advantages as a research method; however, research professionals in the fields of education, government, and business have acknowledged its benefits, but also have some reservations about its use as a valid research process (Sackman, 1975). This controversy has existed for 40 years, but its methodology has been proven to be an excellent way to draw consensus (Delbecq, Van de Ven, and Gustafson, 1986). Its features distinguish it from other methods of group interactions. The beneficial features of this method were identified in a research study conducted by the Society of Manufacturing Engineers (1977). These included the anonymous interaction its gives to participants within the study; the iteration with controlled feedback that takes place during the Delphi rounds; and the statistical group response, which encompasses the ideas of the entire group or panel of experts (Delbecq, Van de Ven, & Gustafson, 1986). The Delphi technique has also been described as a good research method or tool for gathering consensus of opinion in order to determine common goals. Meyers and Booker (1990), in a research guide for the Office of Nuclear Regulatory Research, suggest three main advantages of the use of the Delphi process. First, it is designed to avoid biases that can arise from group dynamics. Second, it is the best method for obtaining detailed information. Third, it uses the experts' problem-solving capabilities and can compile enough information, usually by a mathematical aggregation" (p.98). Fowles (1978) provided two more reasons for choosing the Delphi method. It is appropriate if a topic cannot "lend itself to precise analytical techniques, but can benefit from subjective judgments on a collective basis, and it is appropriate when individuals who need to interact cannot be brought together in a face-to-face exchange because of time or cost constraints" (p. 278). He further states that in a conventional face-to-face setting, strong personalities tends to dominate or give rise to an undesirable "bandwagon" effect (p. 278).

Rationale for Selecting Delphi

The rationale for the selection of the Delphi process for this study included the three main features that the Delphi offers as a research strategy. Dalkey, Rourke, Lewis, and Snyder (1972) identified these as anonymity, controlled feedback, and statistical group response. Another rationale for selecting a Delphi method was its ability to motivate individuals to participate. The feedback process from the group of experts can be novel and interesting, and the use of systematic procedures allows objectivity in the outcomes, which is reassuring to the participants. Finally, the "anonymity and group response allows for the sharing of responsibility to be refreshing and that it releases the respondents from social inhibitions" (Dalkey, Rourke, Lewis, & Snyder, 1972, p. 21). These features made the Delphi process desirable for this study, and, because of the need to develop a practical instrument to be used by the Engineering Graphics Profession, member input was important for acceptance of the findings.

Methodology

This study used a modified three round Delphi method for the development of categories with objectives for assessing introductory courses in engineering/technical graphics. The selection of the 12 expert panel members was based on three criteria. First, the level of education they teach. Four of the panel members represented high school drafting programs with emphasis in both architectural and mechanical drawing, four members of the expert panel represented the community college system or two-year post-secondary programs, and four additional panel members represented the four-year post-secondary system or university system. Second, each panel member had at least 10 years experience teaching in fields related to engineering/technical graphics and were full-time employees. Third, the panel members were recommended by other professionals in the field of graphics (Linstone & Turoff, 1975). Considering time and cost factors, both the high school and community college panel members were teachers in the state of North Carolina and recommended by faculty at NC State University, consultants from the North Carolina State Department of Public Instruction, and the North Carolina Community College State System. The four members selected to represent the four-year university systems were suggested by members of the Engineering Design

Graphics Division of the American Society of Engineering Education, during the Mid-year Meeting in San Antonio, Texas (2001), and provided a balanced representation from all interest and regions of the county. Once the expert panel was selected, the researchers began the Delphi study by asking each member to suggest categories and objectives for assessment. This first round of the Delphi study included example categories and objectives from previous thematic research the authors had conducted over the past three years. Members were allowed to edit, delete, and add to each of the suggested categories and objectives. This included the categories and objectives suggested by the researchers in the first round, which were provided to illustrate the writing style needed for the objectives and as a starting point for the study (Delbecq, Van de Ven, and Gustafson, 1986).

After collecting information obtained from round one, similar objectives and categories were combined and the instrument for round two was developed. In round two, expert panel members were asked to rate each category on a Likert scale of one through five (Linstone & Turoff, 1975).

The third and final round asked expert panel members to rank order, for each category, the objectives left from round two (Clark & Scales, 2001). Expert panel members could not add or edit any objective or category left from the previous round, only rank them starting with "1" as the most important. Once the data were received, the researchers kept the highest 50% ranked objectives for each category, which were used for the study's conclusions and the development of the assessment model presented at the end of this paper (Linstone & Turoff, 1975). By keeping only the upper 50% of the objectives listed by the panel members, it was assured that these objectives were those on which the panel members were in strongest agreement.

Findings

By the beginning of round one of the Delphi Study, the expert panel had added 12 additional categories and 88 additional objectives to those suggested by the researchers. Similar categories and objectives were combined. The researchers also rewrote some objectives for clarity. The panel members were then asked to rate the objectives during round two. The rating system ranged from one to five on a Likert Scale. A rating of one indicated that the rater felt that the practice was very poor and not needed for any introductory graphics course. A rating of two indicated that the rater felt that the assessment was a poor assessment practice that only should be used in 49% or less of all introductory graphics courses. A rating of three indicated that the rater felt that the assessment was a fair assessment practice and is appropriate for 51% or more of all introductory graphics courses, and a rating of four indicated that the rater felt that the good assessment practice that should be used in 75% or more of all introductory graphics courses. A rating of five indicated that the rater felt that the objective was an excellent assessment practice that should be used in 100% of all introductory graphics courses. In the final round (three) the expert panel members were asked to rank the objectives under each category by importance, starting with the number one (1) as a indication of the most important objective. They were also asked to rank the categories by importance in the same fashion. Table 1 provides a list of the assessment objectives that were ranked in the upper 50% under each category. The table also provides the mean and standard deviation for the rating of each of these objectives from round two as well as the average of the ranking of the objectives from round three. Objectives that were added during round two are indicated and were not rated by the panel members during round two. Figure 1 provides a histogram of the ranking of the categories by their importance in an introductory engineering/technical graphics course.

Final List of Categories and Objectives after Round Three

CATEGORY 1: SOLUTION

Objectives:	Mean*	SD*	Avg. Rank**
• The drawing/models accurately represents the solution to the problem.	4.16	1.53	1.64
• Student selects views and creates drawings that fully describes the shape, size and features of the object.	4.91	0.29	2.18
• Proper procedures were followed with respect to the drawing/model solution.	3.67	1.15	4.36
• (n) Student drawings, models, & dynamic media represent and accurate solution to the stated problem.			4.63

CATEGORY 2: DESIGN

Objectives:	Mean*	SD*	Avg. Rank**
• The design meets the functionality required for the project.	4.50	0.80	1.90
• The design was prepared based on the following considerations: manufacturability, cost factors, ease of production, sound engineering practices/procedures and use of standard available parts.	3.25	1.22	2.83
• The design solution shows some originality in thinking.	3.67	1.23	4.32
• Student made appropriate material choices.	3.25	1.14	4.00

CATEGORY 3: STANDARDS

Objectives:	Mean*	SD*	Avg. Rank**
• ANSI standards were followed throughout the drawing/modeling process.	3.92	1.31	1.00

CATEGORY 4: ACCURACY

Objectives:	Mean*	SD*	Avg. Rank**
• Students stay within specified measurements in construction of drawings and models.	4.34	1.23	1.18
• Students stay within appropriate tolerances in construction of drawings and models.	3.5	1.45	2.18

CATEGORY 5: DIMENSIONING

Objectives:	Mean*	SD*	Avg. Rank**
• A completely dimensioned figure includes the sizes and locations of all features.	4.84	0.39	2.64
• Dimensions are placed in the most appropriate views.	4.84	0.39	3.54
• Dimensions follow accepted practices.	4.67	0.65	3.91
• (n) Students demonstrated the correct placement of dimensions.			5.27
• (n) Students demonstrate an understanding of dimensioning through their drawings or solutions.			5.27

CATEGORY 6: GEOMETRIC CONSTRUCTION

Objectives:	Mean*	SD*	Avg. Rank**
• Students understand the relationship between geometric construction and the production of engineering/technical drawings.	4.50	1.21	3.45
• Students are familiar with geometric terms and concepts.	3.84	0.90	3.90
• Students can develop and manipulate geometry in a CAD environment.	4.34	1.23	4.18
• Student uses an efficient construction process.	4.34	1.23	4.18

**Mean and SD from Ratings in Round 2.* ***Average of Ranking from Round 3* *(n) Added during Round 2*

Table 1 (continues on next page)

CATEGORY 7: MODELING

Objectives:	Mean*	SD*	Avg. Rank**
• Student demonstrates the use of an efficient modeling process.	3.92	0.10	2.82
• Appropriate methods are used in construction (Boolean, extrusion, etc.).	3.92	1.16	2.82
• The appropriate geometry was utilized in the construction of the model.	3.67	1.37	4.00
• (n) Student demonstrated computer graphic literacy through 3D modeling and construction exercises.			4.64
• (n) Students can build 3D models for 2D information.			5.90

CATEGORY 8: SECTIONING

Objectives:	Mean*	SD*	Avg. Rank**
• (n) Students should be able to understand when to apply the various types of section views (i.e., full sections, half section, aligned section, offset section, etc.)			2.73
• Correct sectioning style or type is used.	3.50	1.73	4.4
• The cutting plane's path and the direction of arrow(s) should agree with the sectional drawing(s).	4.50	1.24	4.45
• Hatch patterns correctly represent material(s) being used.	4.17	1.53	4.64
• (n) Student includes sectional drawings when they improve the ability of the reader to visualize the object's shape or interior detail.			4.73

CATEGORY 9: SKETCHING

Objectives:	Mean*	SD*	Avg. Rank**
• Students display accurate proportions in their sketches.	4.84	0.58	1.55
• Students can sketch an accurate representation of the problem or solution.	4.50	0.80	1.64

CATEGORY 10: TOLERANCING

Objectives:	Mean*	SD*	Avg. Rank**
• Students are familiar with terms and concepts associated with general tolerancing and geometric dimensioning and tolerancing.	4.00	1.08	1.64
• Students understand the effect that tolerancing has on the production of components in the industrial world.	3.92	1.04	2.18
• Students can apply basic geometric dimensioning and tolerancing concepts to engineering/technical drawing assignments.	3.58	1.19	2.18

CATEGORY 11: LETTERING

Objectives:	Mean*	SD*	Avg. Rank**
• Student can demonstrate neat, legible freehand lettering using all uppercase, vertical, Gothic letters.	3.92	1.44	1.18
• Letter size should be appropriate to the drawing and spaces available while still maintaining legibility.	4.00	1.29	2.27

CATEGORY 12: ORTHOGRAPHIC PROJECTIONS

Objectives:	Mean*	SD*	Avg. Rank**
• Student knows orthrographic projection theory.	4.84	0.39	3.00
• Views are included to completely describe the object's space without unnecessarily duplicating information.	4.84	0.39	3.55
• Views are aligned and placed in correct positions relative tothe other views.	4.50	1.17	4.50
• Visible and hidden lines are projected and arranged so as to correctly represent the object's shape.	4.58	1.16	4.55
• (n) Student can read orthographic drawings.			4.91

**Mean and SD from Ratings in Round 2.* ***Average of Ranking from Round 3* *(n) Added during Round 2*

Table 1 (continued)

CATEGORY 13: PICTORIAL DRAWINGS

Objectives:	Mean*	SD*	Avg. Rank**
• Student is able to identify drawings as either perspective, isometric, or oblique drawings.	4.17	1.27	1.72
• (n) When provided orthographic views or physical models, the student can produce isometric sketches of simple objects.			2.00
• Pictorial drawings include correctly aligned ellipses.	3.91	0.79	4.27
• Student can list at least one advantage and one disadvantage of using oblique or perspective as compared to isometric drawings.	3.50	1.38	4.27

CATEGORY 14: ANIMATION/SIMULATION

Objectives:	Mean*	SD*	Avg. Rank**
• (n) Students can build accurate 3D models for the simulation process.			1.82
• (n) Students understand the animation process.			2.09
• (n) Students understand the value of testing and evaluating through animation or simulation.			2.09

CATEGORY 15: SCALES

Objectives:	Mean*	SD*	Avg. Rank**
• (n) Student should be able to measure using all scales provided on an engineering, metric, and architectural scale.			1.00

CATEGORY 16: AUXILIARY VIEWS

Objectives:	Mean*	SD*	Avg. Rank**
• (n) Student includes auxiliary views when they are needed to improve the ability of the reader to visualize the object's shape.			1.50
• (n) Student is able to identify true length edges and surfaces in parallel projections.			2.50

**Mean and SD from Ratings in Round 2.* ***Average of Ranking from Round 3* *(n) Added during Round 2*

Table 1 (continued)

Additional Items

The categories and objectives below were provided by one of the expert panel members.

CATEGORY: PROBLEM STATEMENT

Objectives:	Mean	SD
• Measure: The problem statement/definition realistically describes a problem whose solution may adequately be met with engineering graphics as the principle medium.	3.42	1.56

CATEGORY: ANALYSIS

Objectives:	Mean	SD
• Student analysis of the problem adequately represents an related examination of similar or solutions.	2.67	1.44

CATEGORY: VISUALIZATION & IDEATION

Objectives:	Mean	SD
• Preliminary concept sketches provide visual evidence of multiple of ideas concerning possible solutions (through visualization sketches).	3.84	1.27

Table 2 (continues on next page)

CATEGORY: DIGITAL GEOMETRIC DESCRIPTION

Objectives:	Mean	SD
• Students develop - demonstrate computer graphic literacy through 3D modeling and construction exercises from concept sketches.	4.00	1.04

CATEGORY: REFINEMENT

Objectives:	Mean	SD
• Students complete and organize digital models and drawings and prepare to analyze, simulate and test model. Includes refining and reviewing accuracy and completeness of project files/models.	3.08	1.26

CATEGORY: DYNAMIC EVALUATION OF SOLUTION

Objectives:	Mean	SD
• Students test and validate solution/design through virtual simulation (graphically) and dynamic techniques, via simulation - scripting and other analysis-validation methods (including accurate 3D animations).	2.75	1.54

CATEGORY: PRESENTATION OF PROTOTYPE SOLUTION

Objectives:	Mean	SD
• Completed drawings, models, and dynamic media accurately represent the solution to the problem via digital CG technology.	3.34	1.65

Table 2 (continued)

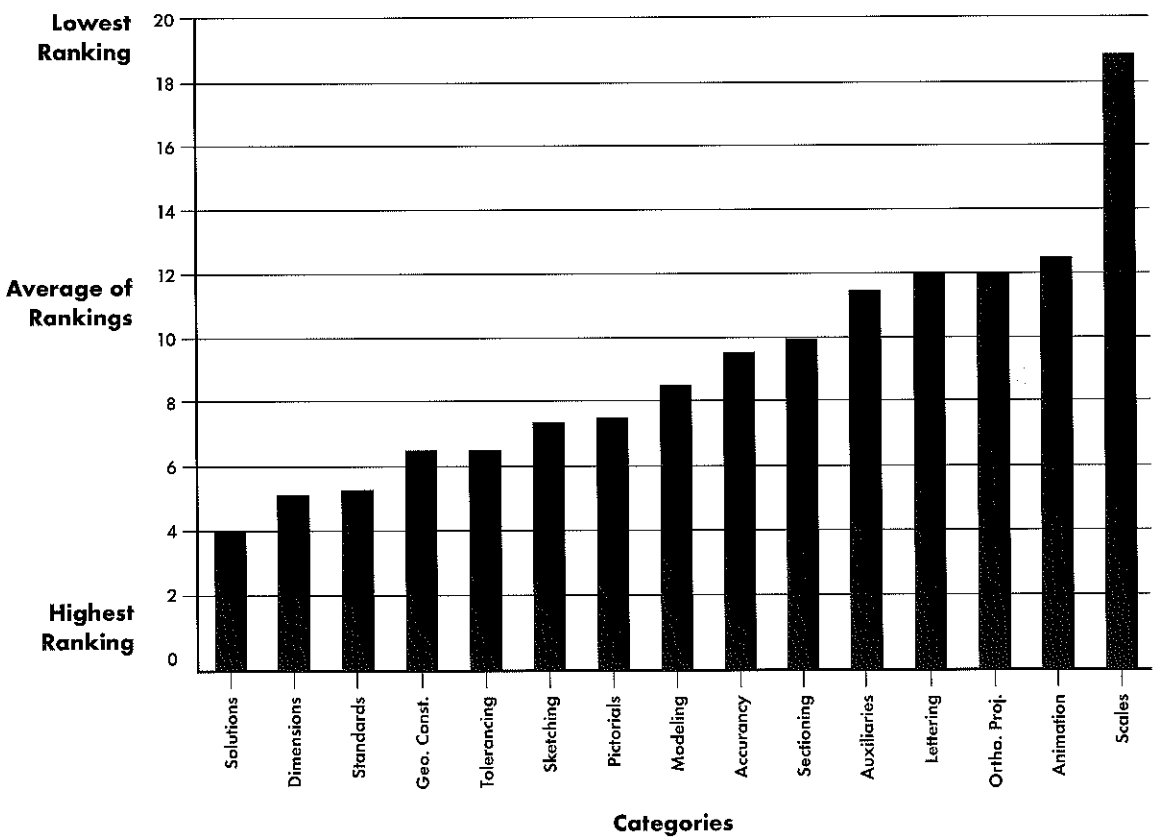

Figure 1 *Average of Ranking of Categories by Expert Panel Members During Round 3*
NOTE: The lower the average of the ranking, the greater the importance of the category as a content area in introductory engineering/technical graphics courses.

Conclusions

In examining the information gathered by the study, a number of things stand out. By the second round, several conclusions could already be reached. First, there is a diversity of opinion between the panel members concerning the appropriate objectives that should be included in an introductory course in engineering/technical graphics. The differences are evident when examining the objectives suggested by instructors in higher education and instructors in high schools. Although many high school programs include work in CAD and solid modeling, it is evident that these instructors still tend to think in traditional course evaluations and content. This suggests that a separate Delphi study might be conducted that examines high school program assessment practices and higher education practices separately. It also suggests that greater attention needs to be paid to the actual content and assessment practices utilized in public schools. If their practices are not appropriate for the current content of their courses, they may need some help in making that transition.

Second, the high school and community college instructors overall provided less input during the delphi process. They seemed more intimidated by the research method.

Third, the study data seems to support the conclusions, from previous studies conducted by these researchers, on trends and issues related to the engineering/technical graphics profession, which will be discussed later in the conclusions (Clark & Scales, 2000).

Fourth, the Delphi process generated a second level of categories from one of the members of the panel. These categories are more broad based and are likely a level between the detailed objectives for assessment and the ultimate goal of providing students with technical visualization skills.

During the third round, the panel members were asked to rank the assessments under each category by importance, using one (1) to indicate the most important assessment objective. Likewise, they were also asked to rank the categories in importance. In examining the results from this round some additional conclusions can be drawn.

First, it is obvious when looking at Figure 1 that many content areas currently taught in introductory courses that would have been ranked higher in the past are no longer considered as important. This is evident when comparing the results of this study to a survey conducted by the researchers in 1999 (Clark & Scales, 2000). In particular the ranking of the importance of Auxiliaries, Lettering, Orthographic Projection, and Scales have placed them at the bottom of the list. Although the panel members indicated that they still need to be part of the course content by their inclusion in the assessment categories, they ranked other areas of assessment higher. This indicates that the shift from manual drawing to computer-aided drawing (CAD) has had an impact on the panel members' teaching priorities.

Second, the data from round three further demonstrated that panel members were not in agreement on the order of importance of objectives under some categories. This was particularly evident in the Solution, Design, Dimensioning, Geometric Construction, and Pictorial Drawing categories. The averages between a large number of the objectives under these categories were numerically very close. In the Solution category, assessment objectives related to standards and modeling had a narrow range of rankings. In the Design category, the averages of five objectives were close. This is probably due to the fact that this is a new content area in several introductory courses; therefore, it is less well defined in the minds of the panel members. In the Dimensioning category, four objectives related to placement of dimensions and standards were numerically close. This may provide evidence that the panel was not sure of the importance of specific standards in our present introductory courses. Even more striking was the small range of numbers in the Geometric

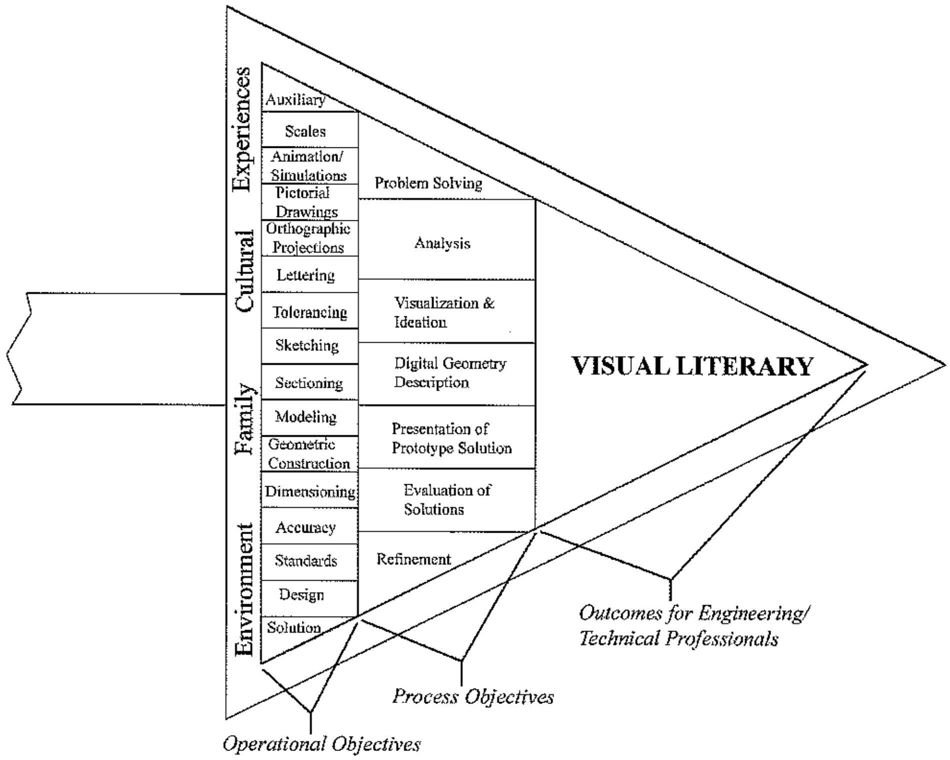

Figure 2 *Model of Assessment Taxonomy for Introductory Engineering/Technical Graphics Courses*

Construction category. The entire listing of eight objectives had a range from 3.90 to 5.20 demonstrating the disagreement among the panelist on the rankings of the objectives under this category. This could also be an indication that the panel members valued the majority of the objectives, and found it difficulty to make a decision about their order of importance.

Finally, Figure 2 is an illustration of the model that the researchers created for an assessment taxonomy for introductory engineering/technical graphics courses based on this study. This model provides a suggested theoretical frame that demonstrates the hierarchical arrangement and levels of an assessment outcome-based taxonomy that includes objectives, broad educational goals, and the final outcome of an introductory engineering/technical graphics course. The layout begins with the background of the student. The next level in the model lists the specific areas that the content of an introductory course should contain. Level three defines more general areas of concepts that can be obtained in both introductory and advanced courses, and the model ends with the main outcome of visual literacy.

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A Design-Based Engineering Graphics Course for First-Year Students

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Abstract

With advances in computer technology and design and graphics practice in industry, the objectives of graphics education have also changed. Increased emphasis has been placed on developing design, teamwork, problem-solving, visualization, and communication skills. This paper describes the first-year Introduction to Design course at Iowa State University. Design for manufacturing and concurrent engineering principles are incorporated into the curriculum. Autodesk Inventor is used as the primary CAD tool for parametric solid modeling. Student teams mimic design companies and complete design projects. A library of 3-D virtual models have been created to replace physical hand-held models previously used to demonstrate the concept of multi-view projections. Mental Rotation Test results show that student spatial visualization skills have been dramatically improved. By the end of the course, most students are able to perform complex design tasks, and the quality of student team projects has also been enhanced.

Introduction

Product design is a critical activity. It has been estimated that 70 - 80% of the cost of product development and manufacture is determined by the decisions made in initial design stages (Kalpakjian & Schmid, 2001, p.9). Thus, product success depends upon efficient design methods.

During the design process, 92% of communications are graphically based (Bertoline, Wiebe, Miller & Mohler, 1997). Graphics is a visual communication language, which helps designers understand their developing designs and to convey their ideas to others. Thus, the ability to effectively transform design ideas into graphics, and then to transform graphic design descriptions into real products, is essential in modern competitive industry.

Most design activities are based on a common 3-D CAD database. Thus, adequate visualization skills are important for creating and understanding the 3-D CAD models used during the design process. A survey published by Barr (1999) shows that developing 3-D visualization skills is ranked as the most important topic in future engineering design graphics education. Prior research also shows that student 3-D visualization ability greatly influences future career success in science, engineering, and technology (McKim, 1980; Norman, 1994; Pleck, Mcgrath, Bertoline, Bowers & Sadowski, 1990).

Therefore, traditional drafter-only training has proven to be insufficient to meet modern industry needs. To produce well-prepared graphics and design professionals, academia must integrate design activities into introductory graphics courses (Buchal, 2001). Technical or engineering graphics programs must revise their curricula to place more emphasis on design principles, teamwork, visualization, problem-solving, and communication skills.

Course Outline

The goals of Iowa State University's Introduction to Design course are to equip students with necessary CAD, design, teamwork, visualization, sketching, problem-solving, and communication skills, to help them succeed in their future careers. There are fifteen weeks in the one-semester course, and each week consists of one hour of lecture and four hours of laboratory. Basically, each week of the course is used to cover one topic. The lecture topics include:

- Introduction to design
- Orthographic projections
- Engineering drawing
- Teamwork and Gantt charts
- Design for manufacturing and concurrent engineering
- Dimensioning
- Fasteners
- Auxiliary views
- Sectional views
- Pictorial views
- Rapid prototyping
- Material selection

The purpose of laboratory exercises is to develop students' CAD, design, teamwork, problem-solving, and communication skills. Now, Autodesk Inventor is the primary parametric solid modeler used in the class. However, three weeks are also spent learning AutoCAD. Basically, each week is used to cover one laboratory topic, and the last three weeks are spent on group design projects and presentations. Contents of the laboratory activities include:

- Feature-based parametric modeling
- Constructive solid geometry (CSG)
- Constraints and relations
- Extrude, cut, revolve, mirror, offset, pattern, loft, sweep, coil, shell, round, and fillet operations
- Sheet metal design
- Assembly modeling
- Presentation animation
- Engineering drawing
- Virtual reality
- Group design projects and presentations

Since the Virtual Reality Applications Center (VRAC) at Iowa State University is available for public tours, and since companies increasingly use virtual reality to verify their designs (Gomes de Sa & Zachmann, 1999; Abshire & Barron, 1998), students in the first year design course are given an opportunity to experience virtual reality as a state-of-the-art design and visualization tool. Each semester we spend one week of laboratory time visiting the VRAC and experiencing VR environments. The VR tour not only inspires students' interest in design and graphics, but also broadens students' knowledge in visualization technology.

Sketching and Visualization Skills

The goal of contemporary design and graphics education is to produce designers rather than drafters. A major aspect of this effort is the development of visualization skills (Newcomer, McKell, Raudebaugh & Kelley, 2001). Many graphics educators believe that working with solid models on a computer screen will enhance students' visualization skills. Devon, Engel, Foster, Sathianathan & Turner (1994) showed that using solid modeling does enhance spatial visualization skills more than using wireframe CAD or teaching graphics in a more traditional way. However, Sorby and Gorska (1998) showed that merely working with 3-D computer models in a solid modeling environment does not develop spatial visualization skills as well as traditional visualization skill-building techniques like sketching. Sorby (1999) concluded that in order to develop 3-D spatial skills, sketching exercises are needed.

There are many contradicting research studies concerning the need for freehand sketching in graphics curricula. In addition, engineers and technicians can now design and manufacture parts without relying on 2-D drawings. However, freehand sketching is still an extremely useful or even necessary skill for engineering design (Newcomer, McKell, Raudebaugh, and Kelley, 2001). Freehand sketching serves as a critical communication and thinking tool for expressing design ideas during conceptual design (Buchal, 2001). After concepts are generated and evaluated, detailed design can proceed, using 3-D modeling tools. Freehand sketching skills are usually built upon 3-D visualization skills. In traditional graphics teaching, instructors use 2-D figures to explain orthographic projection, normal surfaces, inclined surfaces, oblique surfaces, auxiliary views, sectional views, and pictorial views. Using 2-D figures to describe 3-D objects often confuses students. Some teachers

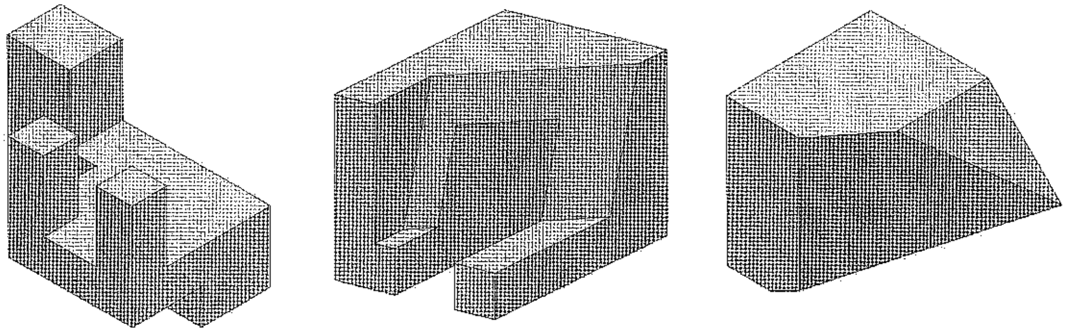
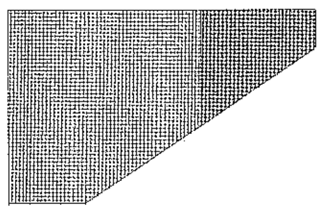
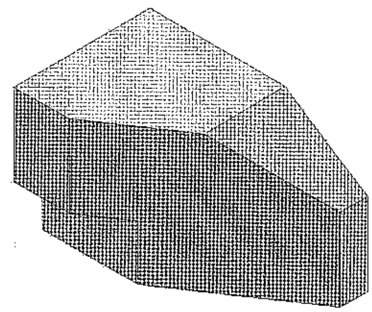


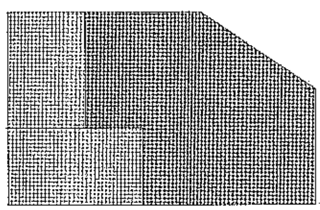
Figure 1 *3-D Solid Models*



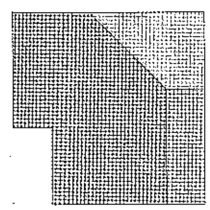
(a) top view



(b) isometric view



(c) front view



(d) right view

Figure 2 *Multiview of a 3-D object*

build simple hand-held physical models (e.g., blocks, wedges, and cylinders) to help students understand 3-D design concepts more clearly. However, for complex objects, physical models are not easy to build or carry.

For the given course, a library of virtual solid models is built using Autodesk Inventor, to replace the physical models previously used for classroom demonstrations. The virtual model library contains models for each freehand sketching topic, e.g., normal surfaces, inclined surfaces, oblique surfaces, spherical surfaces, and auxiliary views. Figure 1 shows some examples of the virtual models. The orthographic front, top, and right side views of a 3-D solid model can be rendered easily using Inventor (Figure 2).

During lecture presentations, the 3-D solid models are projected onto a big screen, using an LCD projector connected to a computer. The instructor can rotate and manipulate the virtual models to show different projection views and, thus, help students visualize the relationships between 3-D models and their corresponding 2-D projections. The instructor also uses the models to demonstrate freehand sketching techniques. Figure 3 shows a snapshot, taken in the classroom, in which a stu-

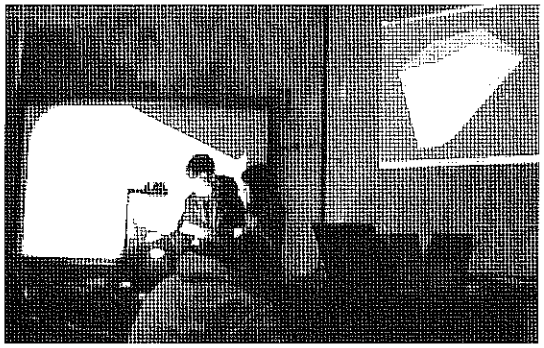


Figure 3 *3-D Model in the Classroom*

dent, guided by the instructor, is sketching 2-D projections, on an overhead projector transparency (left screen), for the displayed 3-D model (right screen). Currently, the virtual models are only used in the classroom. In the future, the virtual model library will be uploaded to the course Website, so that students can access the models at home to help them with their homework assignments.

A survey conducted at the end of the Fall 2002 term shows that 79.4% of students strongly agree or agree that the virtual models, when used in the classroom, help them visualize and understand the relationships between 3-D models and their corresponding 2-D orthographic projections.

Student performance in freehand sketching has also been enhanced. Test scores, when compared with test scores from semesters in which virtual solid models were not used for projection demonstrations, have improved markedly. For example, for questions related to the examples in Figure 4, test scores have improved by 15% and 15.8%, respectively.

Team Project

Student teams are formed at the beginning of each semester, based upon students' answers on a background survey. Four students are assigned to each team. Each team mimics a design company. Several interaction activities are employed to help students become familiar with each other. For example, students are given time to introduce themselves and to exchange email addresses with their teammates, to brainstorm as a team to solve quizzes, and to compete in team puzzle solving competitions.

Students learn a design process consisting of three overlapping parts: ideation, refinement, and implementation (Bertoline, Wiebe, Miller & Mohler, 1997). During ideation, students are asked to choose a product idea and to brainstorm design solutions. Each team then schedules their design work using a Gantt chart. They also develop freehand sketches of their design concepts. Figure 5 shows examples of the freehand sketches done by four student design teams.

During refinement, students brainstorm any necessary design modifications. During refinement, design-for-manufacturing (DFM) and

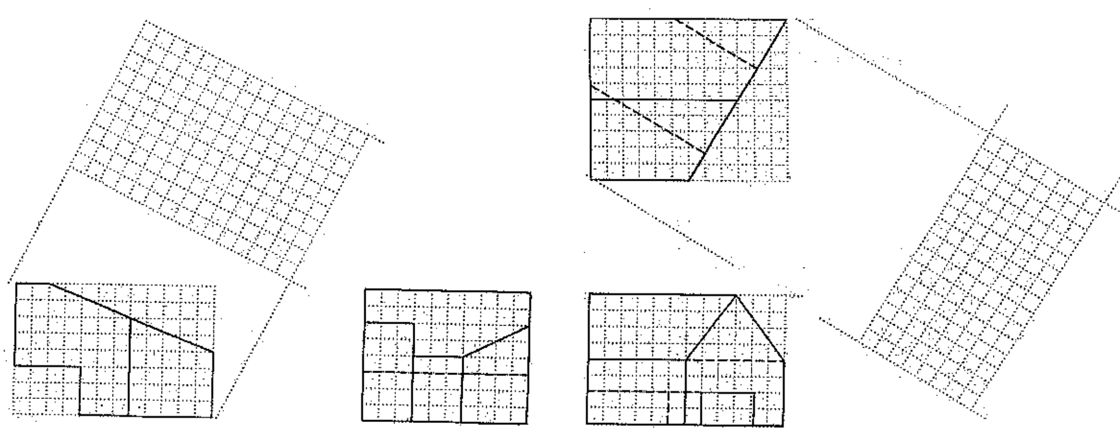
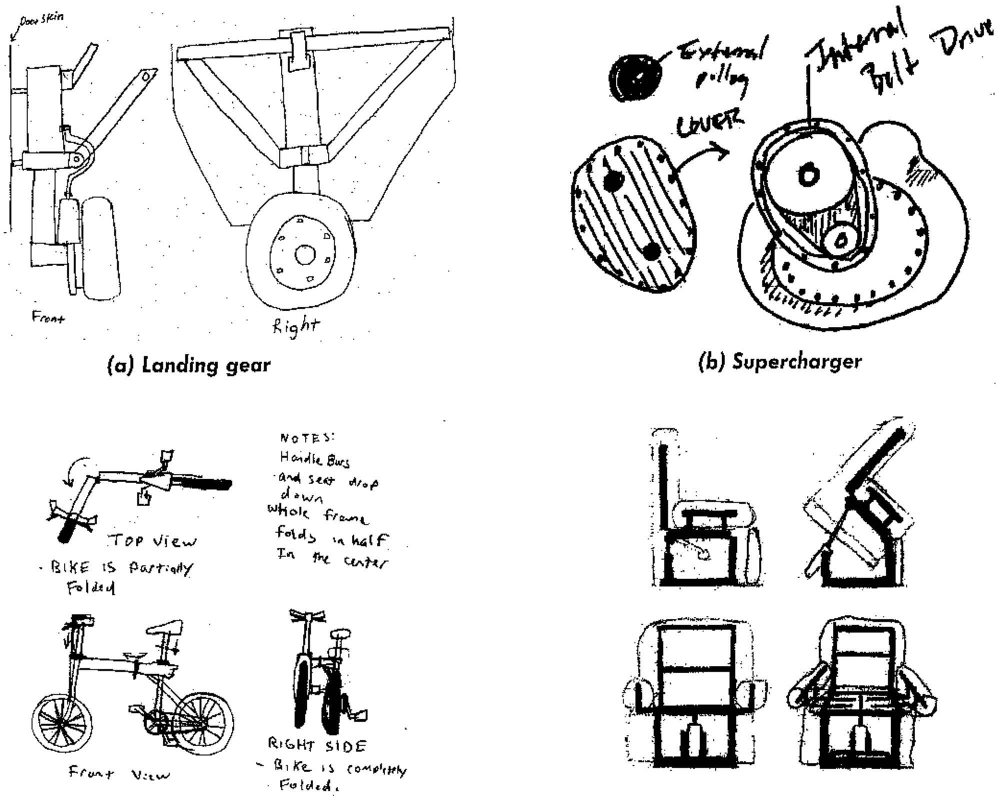


Figure 4 *Freehand Sketching Test (Craig & Craig, 1999)*



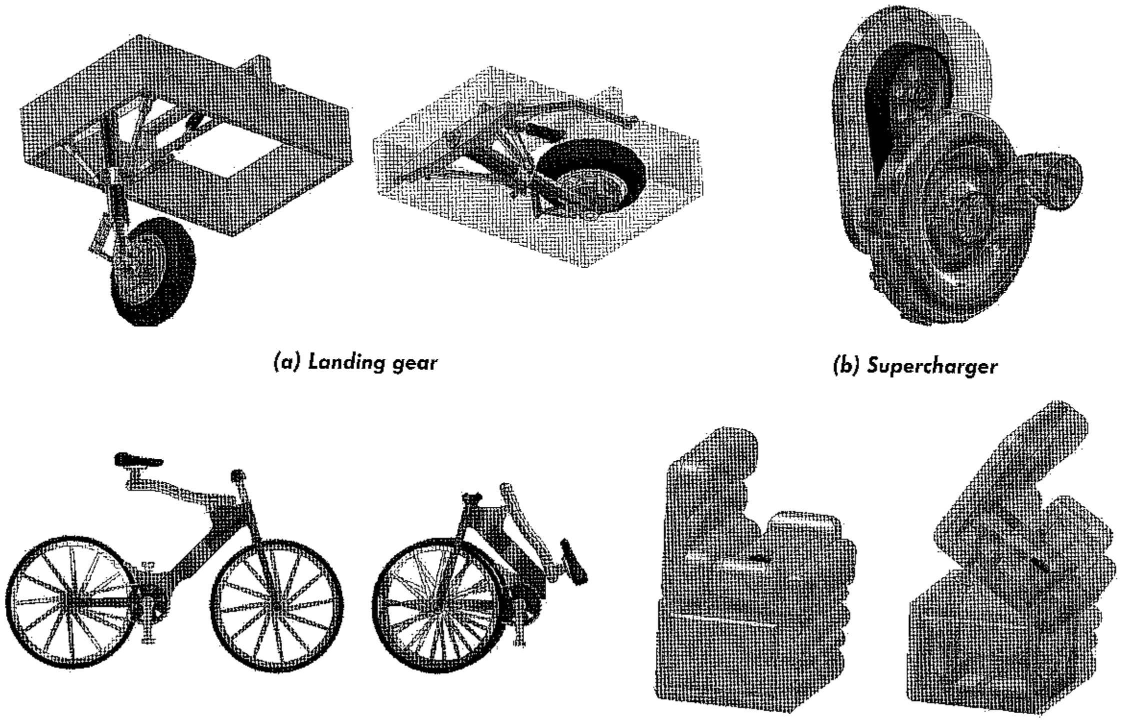
(a) Landing gear *(b) Supercharger* *(c) Folding bike* *(d) Obese chair*

Figure 5 *Ideation Sketches for a Student Team Projects*

concurrent engineering are required elements. Students must determine detailed design and part dimensions. In addition, they must select proper materials.

During implementation, students use Inventor to create CAD solid models for all parts, assembly models, and animation models. Figure 6 shows CAD models of the landing gear, supercharger, folding bike, and obese chair created by four student design teams. Students must create final detail drawings and layout drawings, as well. Finally, students present their designs to the class, using PowerPoint. They also prepare written final reports. The final report must contain a cover page (including a product name, a company name, team members' names, team members' signatures, and a completion date), a table of contents, a brief introduction to the project, the body of the report (including a summary of design problems and solutions, a description of the design process, meeting minutes, Gantt charts, freehand sketches of concept designs, detail drawings, layout drawings, conclusions and suggestions, and any appendices. Students' design skills are improved by participating the design projects. Figure 6 shows that, by the end of the course, students, with only prior high school math, science, and limited drafting skills, can use Inventor to create quite complex designs.

After completing the team project, students complete both a peer- and a self- evaluation for their teamwork. Table 1 shows the teamwork evaluation form used. To prevent bias, the top portion of the evaluation form does not affect students' grades. Tables 2 and 3 show evaluation results for the top portion of the evaluation form. An evaluation conducted at the end of the Fall 2002 term shows that students spend, an average, 20 to 30 hours on their team projects. The results also show that students consistently rate all measured aspects of their projects highly. They show a very positive atti-



(a) Landing gear

(b) Supercharger

(c) Folding bike

(d) Obese chair

Figure 6 *Assembly Model and Animation Simulation*

Project Peer- and Self- -Evaluation

Rate your team on the following criteria (1 being poor, 5 being outstanding)

Project Preparation	1	2	3	4	5
Degree of cooperation	1	2	3	4	5
Degree of confidence	1	2	3	4	5
Quality of presentation	1	2	3	4	5
Quality of PowerPoint file	1	2	3	4	5
Use of time	1	2	3	4	5
Experience working on a teamwork	1	2	3	4	5
Personal design skill enhanced by the project	1	2	3	4	5
How many hours did you spend on your project	0-5	5-10	10-20	20-30	30-?
Overall performance	1	2	3	4	5

Give yourself and your team members up to **25** points **each**:

	Members	**Score**
1	Yourself	
2		
3		
4		

Comments:

Table 1 *Project Peer- and Self- Evaluation Form*

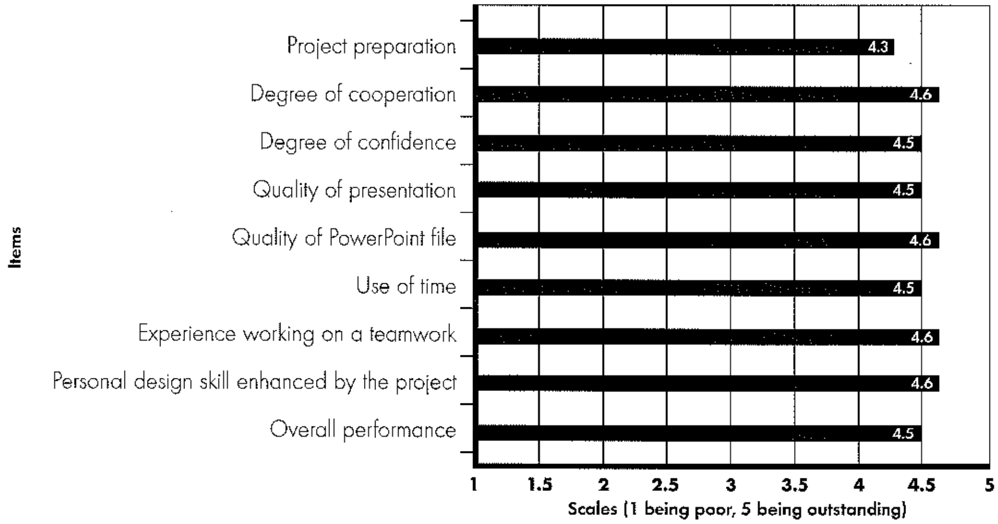


Table 2 *Results of Project Evaluation*

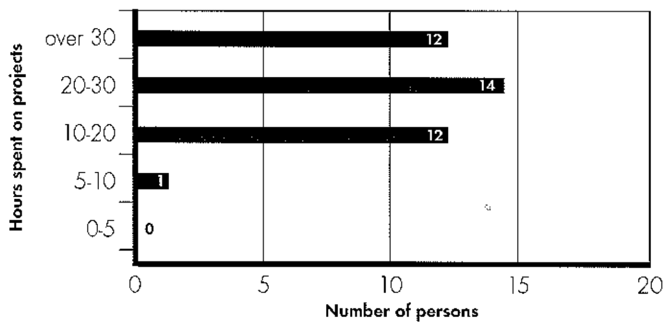


Table 3 *Number of Hours Spent on Projects*

tude toward their design projects, and they enjoy their group project work.

The second-half of the Table 1 survey does affect students' grades. The average score for self-evaluation is 24.9 out of 25, and for peer-evaluation is 23.9 out of 25. Students tend to give themselves higher scores, but peer-evaluation tends to balance self-evaluation scores. Combined, the two scores tend to accurately evaluate students' experiences and contributions to the group projects. Selected student comments include "I enjoyed working with these three guys. We worked well together and had a great time doing this project"; "We worked well as a team"; "We started out slow, that's why the lower scores on the project preparation and use of time; however, we finished very strong once we got going"; "It was hard working in the group because we had similar types of positions; However, our group project turned out great. We all worked hard and made a great product."

Student Feedback on the Course

After finishing the Fall 2002 term, students were surveyed concerning the topics covered in lecture and laboratory (freehand sketching, dimensioning, fasteners, design for manufacturing and concurrent engineering, rapid prototyping, material selection, Inventor, AutoCAD, layout drawing and detail drawing, animation of 3-D assembly models, teamwork, and virtual reality tour). There were three questions in the topic survey.

The first question was, "Which three of the following topics did you find the most interesting?" The top three responses to the question were: Inventor (94.1%), animation of 3-D

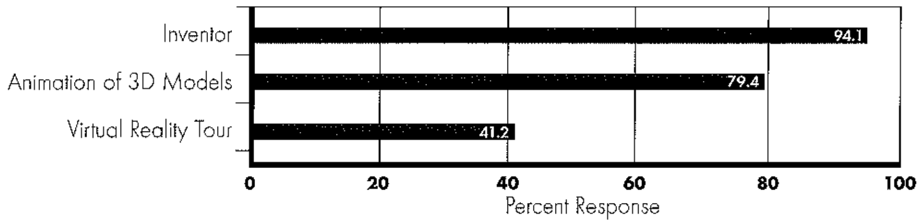


Table 4 *The Most Interesting Topics*

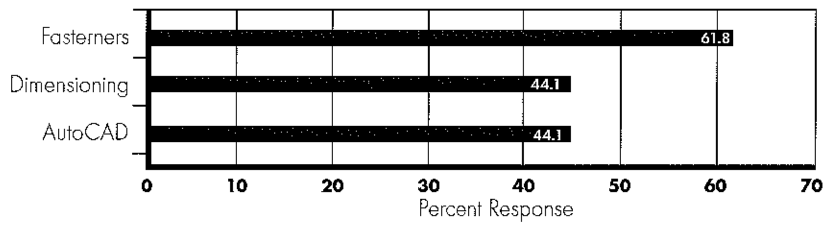


Table 5 *The Least Interesting Topics*

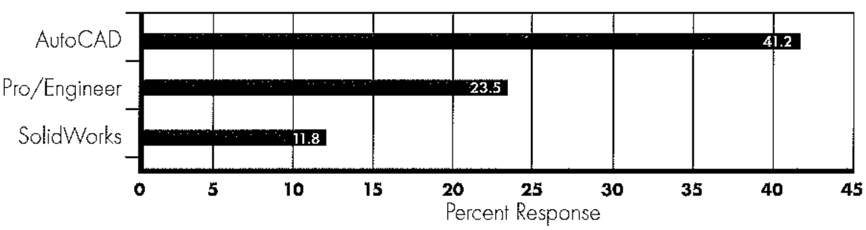


Table 6 *Preferred Secondary Software*

assembly models (79.4%), and virtual reality tour (41.2%) (Table 4). The results shows that, since most students in the course are visual learners, they are more interested in instruction based upon motion pictures or images. The number of students who rate learning Autodesk Inventor as their first choice is very high; students apparently enjoy using Inventor for design tasks.

The second question was, "Which three of the following topics did you find the least interesting?" The top three responses to the question were: fasteners (61.8%), dimensioning (44.1%), and AutoCAD (44.1%) (Table 5). Compared to the Inventor 3-D parametric solid modeler, AutoCAD is less user-friendly and, apparently, less attractive. Beginning design students do not enjoy AutoCAD as much as Inventor. However, one reason for keeping AutoCAD in the curriculum is that most students expect and want to learn AutoCAD before they enroll in the course. Responses to the third survey question reflect students' expectations.

The third question was, "Which alternative for the secondary software tool used in the laboratory do you prefer?" The top three responses to the third question were: AutoCAD (41.2%), Pro/Engineer (23.5%), and SolidWorks (11.8%) (Table 6). The expressed preference might be determined by students' prior CAD knowledge, background, or the old University course catalog. Since most incoming students have heard about AutoCAD before, although they choose AutoCAD as one of the least interesting topics, they still think it is a necessary tool to learn. Usually, several students from the University's pre-architecture program take the course. They might influence the results, as well, since AutoCAD training is highly recommended for architecture students.

Mental Rotation Test

At the beginning of the Fall 2002 term, students took a pre- Mental Rotation Test (MRT) (Vandenberg & Kuse, 1978). The MRT is a standard test used to assess spatial visualization ability. The MRT consists of 20 questions. Each question has two and only two correct answers. For two correct answers, students receive two points. For one correct and one incorrect answer, or two incorrect answers, students receive zero points. If only one answer is given, and it is correct, students receive one point. Students have 6 minutes to finish the test.

The average pre- MRT score was 18.06, with standard deviation 6.30. At the end of the course, students took the MRT test again. The average post- MRT score was 27.37, with standard deviation 6.93. One-way analysis of variance for the pre-test and post-test scores shows that, with greater than 95% confidence ($\alpha = 0.05$), the difference in mean scores is statistically significant. MRT scores from the beginning to the end of the semester improved dramatically. The results show that the students, after taking the course, have stronger spatial visualization skills. Figure 7 shows the distribution of results, sorted by post-test scores; trend lines have been added to more clearly illustrate the measured gains in spatial visualization skills.

Conclusion

Constructing the best design and graphics curriculum and choosing the best technology to enhance students' learning are always major challenges for graphics educators. This paper describes the new curriculum in the first-year Introduction to Design course at Iowa State University. Physical models have been replaced by a virtual model library. Students can now visualize the relationship between 3-D objects and their corresponding orthographic or auxiliary views by manipulating the virtual models. Student surveys show that students believe that virtual model demonstrations help them visualize the relationships between 2-D projections and 3-D objects and enhance their freehand sketching skills. Most students strongly agree or agree that the virtual models help them understand multi-view projections.

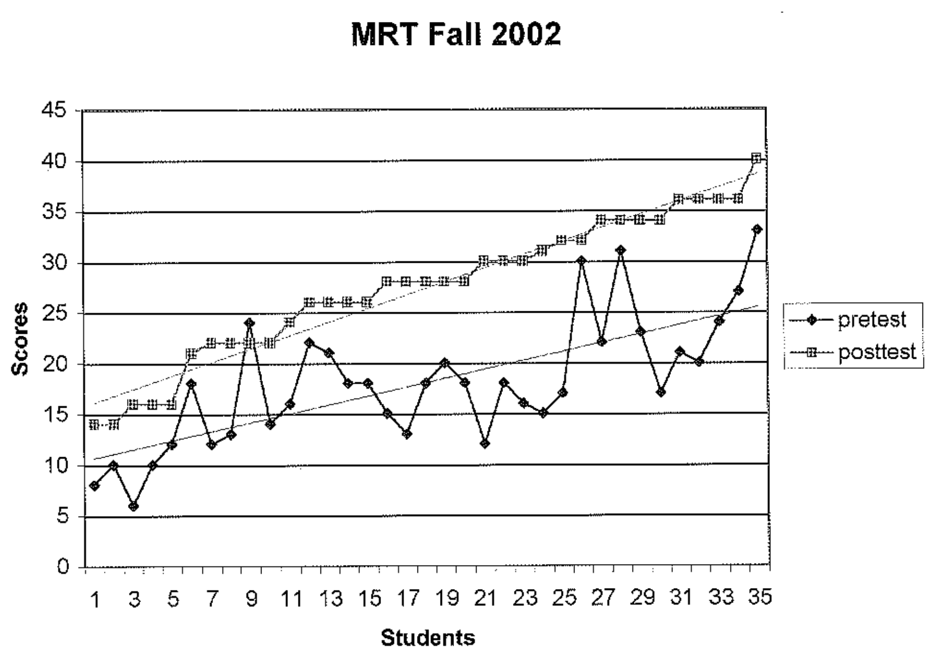


Figure 7 Pre- and Post- MRT

Students now learn basic design-for-manufacturing and concurrent engineering principles and apply the principles in team projects. Autodesk Inventor has replaced Mechanical Desktop and AutoCAD as the primary design tools. By the end of the course, students, with only prior high school math, science, and limited drafting skills, can create quite complex and high quality designs using Inventor. Although, at the beginning of the course, a few students were not interested in teamwork, by the end of the course, they all enjoyed their teamwork experiences and were satisfied with their performance working in a team.

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Resolution

Frank M. Croft, Jr.
2003 National Meeting Resolutions Chair

Whereas the Annual Conference of the Engineering Design Graphics Division of the American Society for Engineering Education has occurred at the Nashville Convention Center in Nashville, Tennessee from June 22-25, 2003;

And, whereas program chair Frank Croft of The Ohio State University provided us with a coordinated program and a suitable forum for the exchange of ideas, methodologies, and conviviality;

And, whereas a Division members, and guests, have enjoyed excellent presentations, wonderful tours, the environs, ambiance, weather, country music and great food of Nashville, Tennessee;

And, whereas Jerry Vinson, Fritz Meyers, and Ron Pare' administered an excellent National Engineering Design Graphics Competition which attracted entries from across the country and was sponsored by Kendall-Hunt Publishing, AutoDesk, Inc., Solidworks, Inc., and Schroff Development Corporation;

And, whereas the Division recognized Edward Dale Galbraith as the recipient of the 2003 Distinguished Service Award for his outstanding contributions to the Division and engineering education;

Now, therefore it is resolved that the Engineering Design Graphics Division of the American Society for Engineering Education extends its thanks and appreciation to the aforementioned organizations and individuals.

Copies of this resolution shall be transmitted to these individuals and shall be spread on the records of the division.

EDGD
ENGINEERING DESIGN GRAPHICS DIVISION
ASEE

58th annual midyear meeting

November 16-18, 2003
Old Town Hotel and Conference Center
Scottsdale, Arizona

"An Expanded World of Technical and Engineering Graphics"

The theme for the 58th annual Midyear Meeting is "An Expanded World of Technical and Engineering Graphics". Papers exploring teaching, practice, and research into Technical and Engineering Graphics are being solicited. Topics that expand traditional engineering graphics into business, government, military, medical, and scientific fields are encouraged. If you are interested in being a part of this Midyear Meeting please contact the program chair.

Dr. Mary A. Sadowski, Program Chair
Associate Dean
School of Technology
Purdue University
masadowski@tech.purdue.edu

American Society for Engineering Education

[2003 ASEE National Design Competition Engineering Design Graphics Division]

results

Virginia Tech Sweeps National Design Contest

Dr. Steve York's students from the Engineering Fundamentals Division of the Virginia Polytechnic Institute & State University put on a real clinic for the rest of EDGD by sweeping the 1st, 2nd, and 3rd place honors in the EDGD 2003 National Design Contest. Two of his entries ran the course with 100% accuracy and impressive speed. The difference between the top two entries was very slight, but stylish design and simple, but effective steering proved to be the winning combination.

Prizes for the top five teams include student editions of both the Autodesk Inventor Suite, and the SolidWorks student edition. The first place team will also divide $2000 in scholarship cash for their excellent design work. Judges for this year's competition were Dr. Ron Pare, Mr. Fritz Meyers and Dr. Jerry Vinson.

Scholarship donors for this year are SDC (Schroff Development Corp.), Kendall-Hunt Publishing Co., McGraw-Hill Publishing, and an anonymous member of the EDGD. Next year we hope to have even more scholarships and prizes for as many teams as we can accommodate. Give your students a chance to win some prizes and some recognition for your program. Even if they do not win, it looks good on a student resume to be able to say "my design team represented our university in a national competition".

Samples of the winning reports and a video of the winning performance will be posted on the contest web sight at http://edg.tamu.edu/asee_nedgc (please note that there is an underscore between asee and nedgc..."asee_nedgc") by August 1, 2003.

Also the criteria for the **2004 CONTEST** "Sudden death, free throw shooter" will be posted at that time. We hope to see lots of entries for next years MAY MADNESS 04' design contest because we plan to have lots of prizes. If you have interest in being a judge or helping to administer the contest please contact Dr. Jerry Vinson at "vinson@entc.tamu.edu"...he is an equal opportunity task master.

The winning teams from Dr. York from Virginia Tech are:

1st Place
"NIGHTRIDER"
Christopher Spider
John Carpenter
Michael Weronski
Jung Hoon Lee

2nd Place
"SCHWERMOBILE"
Darren Branch
Brandon Cox
Chris Hall
Dan Safronoff

3rd Place
"RAGING RED AIR-POWERED CORVETTE"
Bradley Cline
Chris Hillerich
Paul Landers
Nick Liner

The fourth and fifth place honors went to teams from The Ohio State University entered by Professor Fritz Meyers.

4th Place
"X-1...THE BEARDED BEACHCOMBERS"
Pat Muckerman
Ben Turner
Tom Wangler
Troy Wine

5th Place
"X-3...STABBING IN THE DARK"
Zac Altenau
Daniel Henry
Emily Roland
Nick Zachrich

editor's award

Congratulations

2003 Editor's Award Recipients
for most outstanding paper published in Volume 66 of
The Engineering Design Graphics Journal

Qiuli Sun and Kurt Gramoll

The University of Oklahoma

"Internet-based Distributed Collaberative Geometric Modeling"

election results

Congratulations

Holly Ault

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[Calendar of Events]

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58th Annual EDGD MidYear Conference
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November 16-18, 2003
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Program Chair: Mary Sadowski

59th Annual EDGD MidYear Conference
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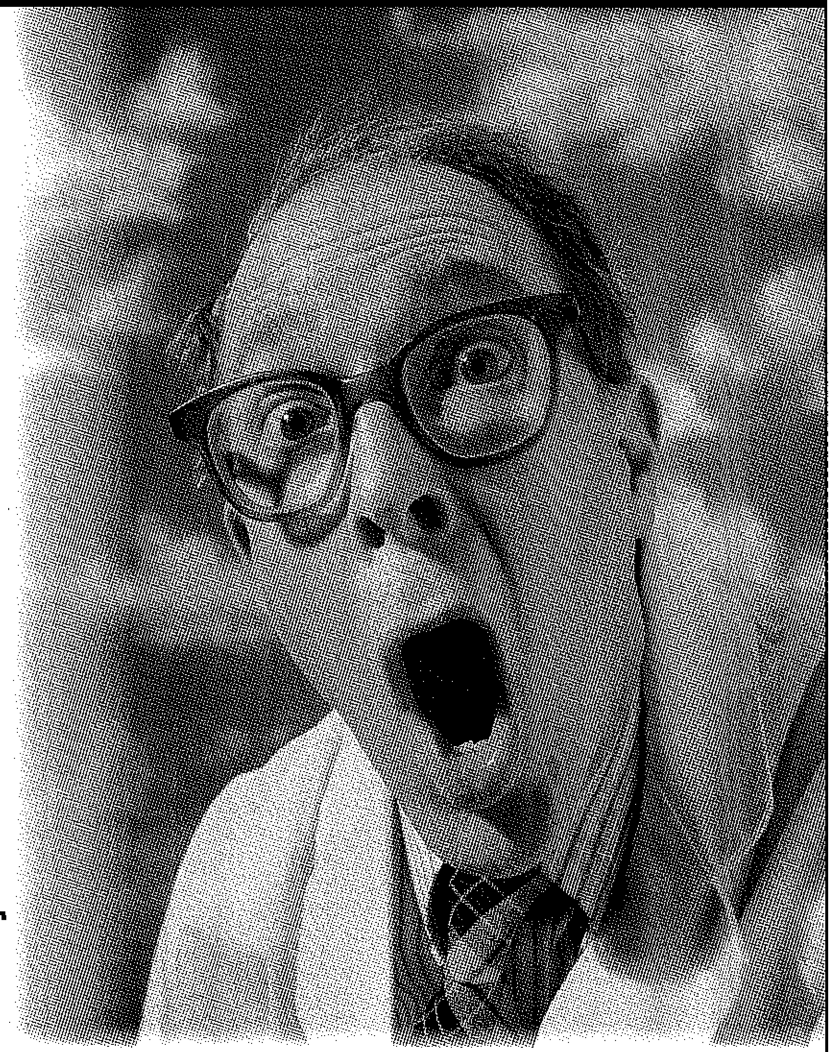

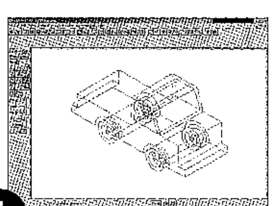

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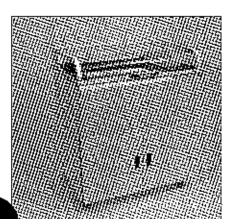

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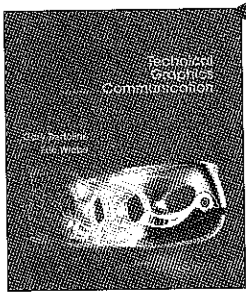

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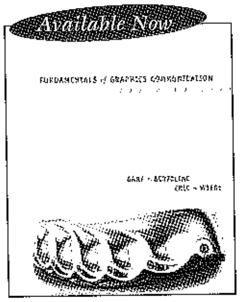

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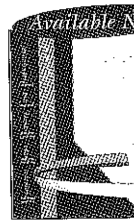

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