The Role of Graphical Communication Outcomes in ABET Criteria 3-g

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Abstract

Graphics has always been a requisite form of communication for engineering practice. The history of major engineering accomplishments is replete with examples of graphical communications: from styli etchings on clay tablets, to near-recent blueprint drawings, to current 3-D computer models. ABET Criterion 3(g) states that students must possess an “ability to communicate effectively.” While the communication modes are not explicitly stated by ABET, many engineering programs interpret this criterion 3(g) to be “ability to communicate effectively in written, oral, and graphical forms.” Thus, there is a strong argument that engineering faculty should address the graphical communication abilities of their students, along with all their other outcomes assessment practices. Results of a recent survey conducted by the authors suggest an extensive list of student outcomes for engineering graphical communication, as mandated by the new ABET EC2000 outcomes requirement criterion 3 (g). These graphics outcomes, and accompanying performance criteria, represent a consensus of current thinking on engineering graphical communication in engineering education.

Introduction and History

Graphics has always been the language of engineering and the preferred media for conveyance of design ideas. The first record of what appears to be an engineering drawing is a temple plan from 2130 B.C. The temple plan was found inscribed on the tablet that is part of a statue (Figure 1). The statue includes a stylus and a notched bar that resembles a scale. The headless statue shows Gudea, a builder and governor of the country later known as Babylon. From Egyptian times, dated about 1500 B.C., papyrus remnants have been found of drawings that used a grid of straight lines made by touching the papyrus with a string dipped in ink pigment, thus setting the stage for early “drafting” practices. The first written record discussing drafting and the use of geometry for design representation is given by Vitruvius, a Roman builder from the turn of A.D. In his “Ten Books of Architecture” [1] he writes how “an architect must have a knowledge of drawing so he can make sketches of his ideas.”

There are interesting records of how great Roman builders used paved city squares as drawing boards. Full size elevation details were chiseled into the stone pavement and used to cut marble blocks that would then fit the erected building with required precision (Figure 2). In about 1500 A.D., the first record of what could be called related multi-view projections appeared in Renaissance Italy. Some of the engineers and inventors of that time were also famous artists. Drawings left by Leonardo da Vinci (Figure 3) were artistic pictorial sketches that resemble axonometric sketching techniques still in use today.

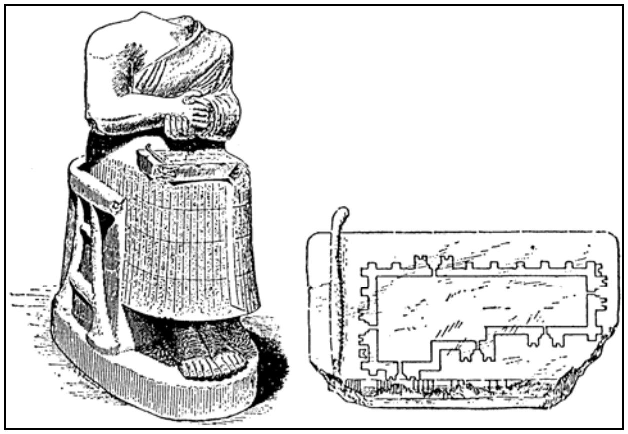

Figure 1: An Early Form of Engineering Graphical communication Shows Stylus Etching on a Clay Tablet Showing the Plan for a Temple.

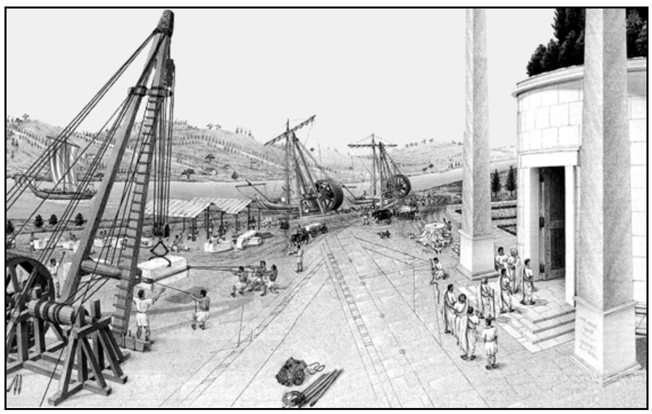

Figure 2: Roman Builders Engraved Details of Buildings on Pavement.

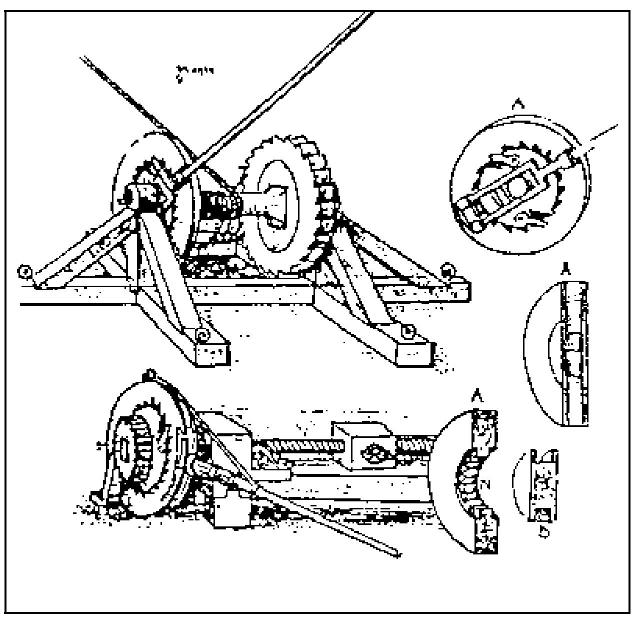

Figure 3: Renaissance Sketches by Leonardo da Vinci Used Techniques Still Common Today.

In 1795, Gaspard Monge published his well-known treatise on Descriptive Geometry, which provided a scientific foundation to Engineering Graphics [2]. Monge was a mathematician who was assigned to the drafting section of a military school in France. While working on fortification projects, he replaced the computed measurement method with graphical solutions that considerably shortened the time necessary to produce solutions to spatial problems (Figure 4). The method of Descriptive Geometry maintained a lofty theoretical position in engineering graphics education for almost 200 years.

During the past two centuries, engineering graphics used different manual tools that made production of orthographic projection drawings easier. Drafting boards, T-squares, and mechanical pencils were common equipment purchased by engineering students. Typical work rooms, such as shown in Figure 5 with engineers huddled over large drafting boards, were emblematic of the practice of engineering for the better part of the past century. The development of the computer hailed yet a new era in engineering graphical communication technology. The first application of computers to engineering design communication resulted in Computer-Aided Design and Drafting (CADD) systems that replaced drawing boards with an electronic tool (Figure 6). The main advantage of CADD was in speeding up the production and revision of engineering drawings, as well as in encoding them into an electronic format for easier information exchange. More recently in the past decade, these CADD systems have been extended to include three-dimensional geometric modeling with the capability of solving the spatial problems of design representation directly in 3-D space.

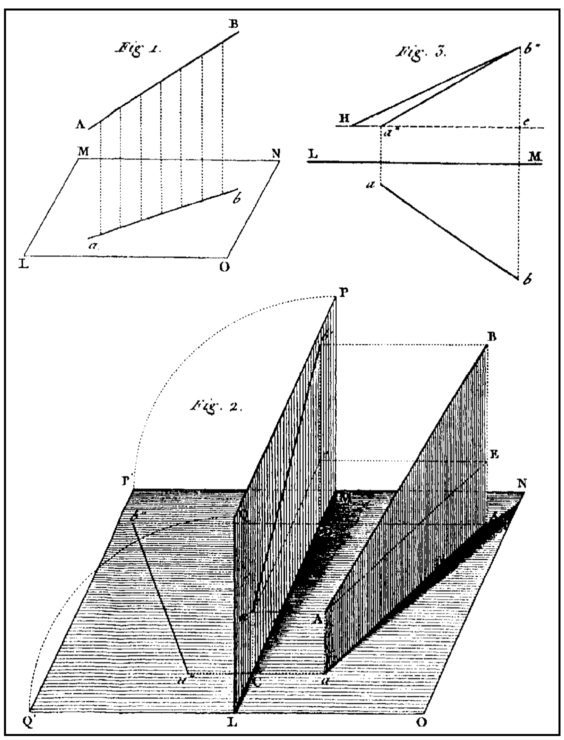

Figure 4: The Method of Descriptive Geometry Used Graphical Projection Principles to Solve Spatial Problems.

Figure 5: Engineers Huddled Over Large Drafting Tables Were Emblematic of engineering for Most of the Past Century.

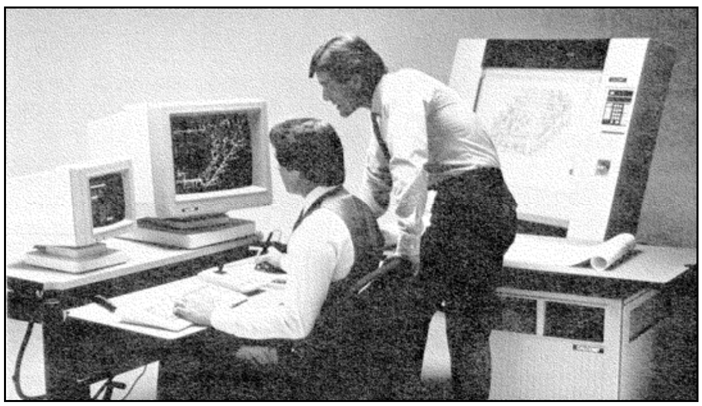

Figure 6: The Early Use of Computers for Engineering Graphical Communication Consisted of Electronic Drafting Systems.

The 3-D Solid Modeling Era in Engineering Education

Within the past decade of the 1990's, the teaching of 3-D solid modeling has become the central theme in most engineering graphics programs. This recent paradigm shift to 3-D has been facilitated by the development and low-cost availability of solid modeling software that allows the student to focus on the "bigger-picture" approach to engineering graphical communication. In this Concurrent Engineering approach [3], the 3-D geometric database serves as the hub for all engineering communication activities (Figure 7). These communications include engineering analysis, simulation, assembly modeling, prototyping, and final drafting and other documentation. In the Concurrent Engineering paradigm for graphical communication, the student starts with a sketch of an idea (Figure 8A). The sketch idea can then be used to build a solid model of the part (Figure 8B). The solid model not only serves as a visualization modality, but it also contains the solid geometry data needed for engineering analysis. Typical of these analyses are finite element meshing (Figure 8C), stress and thermal studies, mass properties reports, and clearance-interference checking. After analysis, the same geometric database can be used to generate final communications like engineering drawings, marketing brochures, and even rapid physical prototypes that can be held in one's hand (Figure 8D).

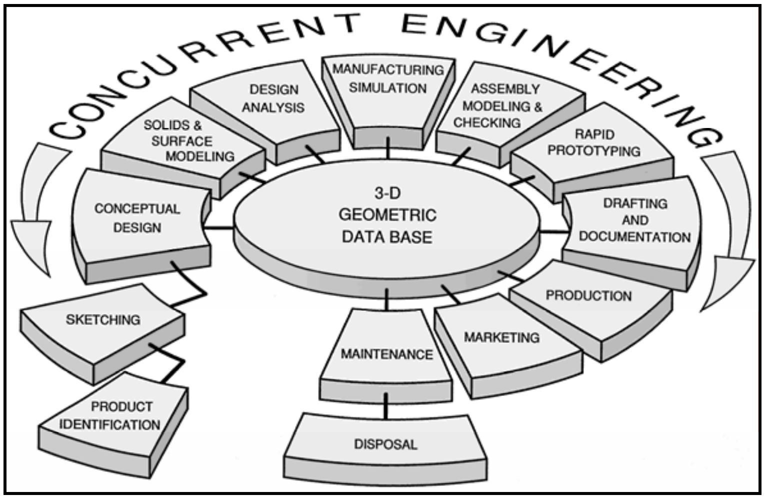

Figure 7: The Concurrent Engineering Paradigm Has the 3-D Geometric Model Database as the Center of All Communication

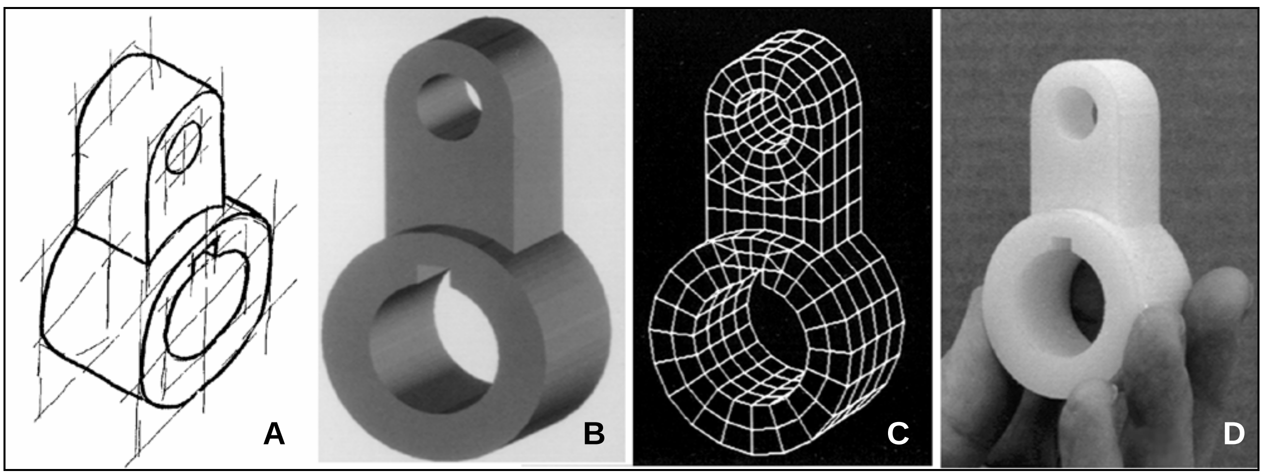

Figure 8: The Modern Engineering Graphical Communication Process Starts with a Sketch (**A**). The Sketch Idea Is then Transformed into a Solid Computer Model (**B**). The Model Geometry Can Be Analyzed for certain Properties (**C**) and a Physical Prototype Can be Produced (**D**).

ABET EC2000 Criterion 3(g)

The new ABET EC2000 Criteria [4] have profoundly changed the way engineering faculty must review their undergraduate curriculum. In previous decades, starting in the 1930's, the ABET accreditation process primarily looked at the inventory of courses that the department offered to see if it met minimum credit-hour standards for topics in basic science and mathematics, engineering science including design, and the liberal education core. The new ABET standards require an outcomes-based approach. Each program is expected to define a set of student outcomes, which are the knowledge, skills, and abilities that must be attained at graduation. Then the engineering programs must continually assess its constituents, including students and alumni, to determine if the outcomes are being achieved.

Although engineering programs are encouraged to define their own student outcomes, a recommended list of eleven outcomes are presented in ABET Criterion 3 (items a to k). One such criterion 3(g) states that students must possess an “ability to communicate effectively.” While the communication modes are not explicitly stated by ABET, many engineering programs interpret this criterion 3(g) to be “ability to communicate effectively in written, oral, and graphical forms.” Thus, there is a strong argument that engineering faculty should address the graphical communication abilities of their students, along with all their other outcomes assessment practices.

Developing Student Outcomes for Engineering Graphical Communication

In an effort to attain consensus on student outcomes for engineering graphical communication, a survey was conducted at the Midyear Meeting of the Engineering Design Graphics Division of ASEE in Scottsdale, Arizona in November 2003 [5]. This survey presented a list of potential graphical communication outcomes derived from a literature search of related journal papers [6]-[9]. This resulted in a list of fourteen major graphics outcomes, and included a sub-list of performance criteria that demonstrate the achievement of that outcome. In all, over 80 questions were posed to the faculty respondents (N=24), who were asked to rank each outcome or performance criteria using a numerical scale of:

5 = Very Important
4 = Important
3 = Somewhat Important
2 = Not Important
1 = Not Important at All

The following lists the fourteen engineering graphical communication outcomes and performance criteria that were posed in the survey.

- **Outcome 1**: *Ability to Sketch Engineering Objects in the Freehand Mode.* This outcome includes making sketches in isometric, oblique, perspective, orthographic, and auxiliary view modes. It also includes freehand lettering and freehand dimensioning.
- **Outcome 2**: *Ability to Create Geometric Construction with Hand Tools*. This outcome includes using hand tools to draw parallel and perpendicular lines, and to construct circles, arcs, tangencies, and irregular curves.
- **Outcome 3**: *Ability to Create 2-D Computer Geometry*. This outcome includes setting up grids and units. It also includes creating and editing 2-D computer geometry, and constructing lines, primitives, arcs, and fillets.
- **Outcome 4**: *Ability to Create 3-D Solid Computer Models*. This outcome deals with the ability to extrude and revolve 3-D parts. It includes adding and replicating 3-D design features such as shown in Figure 9.
- **Outcome 5**: *Ability to Visualize 3-D Solid Computer Models*. This is a companion outcome to Outcome 4 and includes setting view direction, panning, and zooming the model, and setting other view controls.
- **Outcome 6**: *Ability to Create 3-D Assemblies of Computer Models*. This outcome deals with mating several parts into a computer assembly model as shown in Figure 10.

- **Outcome 7:** *Ability to Analyze 3-D Computer Models.* This outcome pertains to analysis of the computer model, including measuring geometry, obtaining mass properties, or creating a mesh to perform a finite element study (Figure 11).
- **Outcome 8**: *Ability to Generate Engineering Drawings from Computer Models*. This outcome includes projecting a drawing from a solid model (Figure 12) as well as completing the drawing with drafting details.
- **Outcome 9:** *Ability to Create Section Views*. This outcome deals with section views in 2-D and 3-D (for example, as shown in Figure 13).
- **Outcome 10**: *Ability to Create Dimensions*. This outcome includes applying standard vertical, horizontal, radius, diameter, and other dimensions to an engineering drawing.
- **Outcome 11**: *Knowledge of Manufacturing and Rapid Prototyping Methods*. This outcome deals with common shop and manufacturing processes that impact drawings, as well as modern rapid prototyping methods.
- **Outcome 12**: *Ability to Solve Traditional Descriptive Geometry Problems*. This outcome covers the classical projective solutions to spatial problems.
- **Outcome 13**: *Ability to Create Presentation Graphics*. This outcome includes creating data graphs and charts, generating color raster images, and creating animations and slide show presentations.
- **Outcome 14**: *Ability to Perform Design Projects*. This final outcome deals with team work, technical reporting, the design process, and reverse engineering.

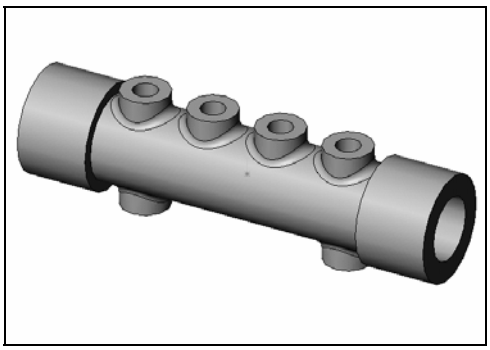

Figure 9: Building a 3-D Part and Applying Design Features.

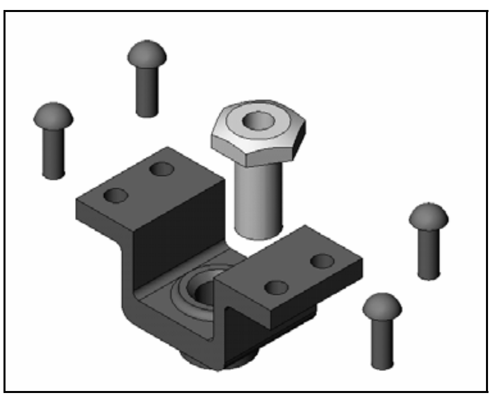

Figure 10: Mating 3-D Parts into a Computer Assembly Model.

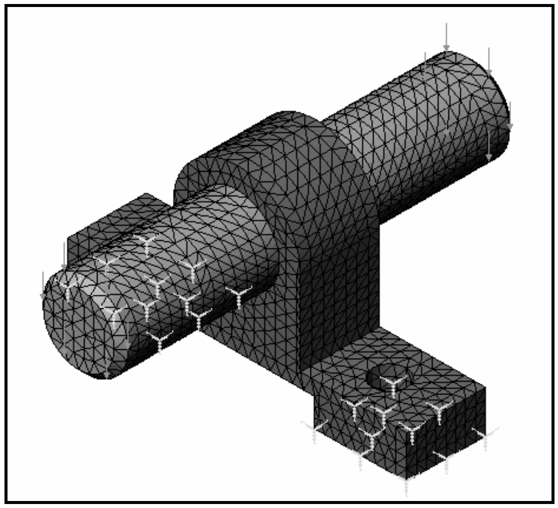

Figure 11: Creating a Mesh in Preparation for a Finite Element Study.

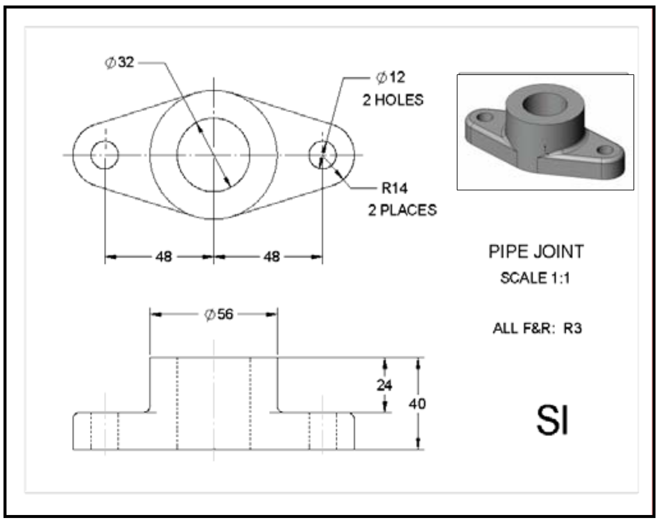

Figure 12: A Final Drawing Projected Directly from The Solid Model.

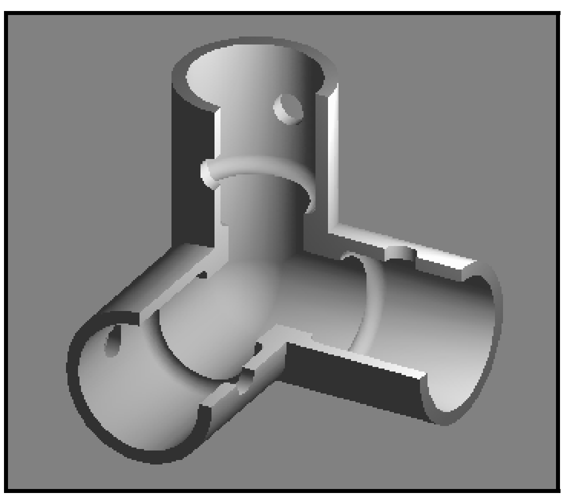

Figure 13: A 3-D Section View of a Part Showing Internal Features.

Outcomes Survey Results

The survey results for the proposed fourteen graphical communication outcomes are shown in Table 1I, listed from highest to lowest ranking. The highest ranked outcome was Outcome 4, ability to create 3-D solid computer models. This supports the earlier contention that "3-D solid modeling has become the central theme in most engineering graphics programs." Indeed, four of the top seven ranked outcomes pertain to modern computer tools to generate a graphical image. In addition, several traditional graphics topics (sketching, dimensioning, engineering drawings, and section views) were also ranked high, receiving average rankings above 4.10. On the other hand, the long-standing traditional topics of Descriptive Geometry and manual geometric construction techniques, were soundly rejected by the respondents. They were the only two topics that received average rankings below 3.00, and significantly below at that.

In addition to the rankings of the fourteen major graphics outcomes, the survey also polled the performance criteria for each outcome. As an example, the results of the performance criteria rankings for Outcome 1, ability to sketch in the freehand mode, are shown in Table 2. It can be seen that some sketching modes (isometric and orthographic) are deemed highly pertinent, while other sketching modes (oblique and perspective) were rejected. Comparable variations in the performance criteria rankings were true for the other 13 major outcomes [10].

Table 1: Ranking of Fourteen Proposed Graphical Communication Outcomes (Listed from Highest to Lowest Ranking).

Proposed Graphics Outcome	Average Rank
4. Ability to Create 3-D Solid Computer Models	4.75
1. Ability to Sketch Engineering Objects in the Freehand Mode	4.67
5. Ability to Visualize 3-D Solid Computer Models	4.46
10. Ability to Create Dimensions	4.38
8. Ability to Generate Engineering Drawings from Computer Models	4.33
6. Ability to Create 3-D Assemblies of Computer Models	4.29
3. Ability to Create 2-D Computer Geometry	4.21
9. Ability to Create Section Views	4.13
14. Ability to Perform Design Projects	3.96
7. Ability to Analyze 3-D Computer Models	3.71
11. Knowledge of Manufacturing and Rapid Prototyping Methods	3.42
13. Ability to Create Presentation Graphics	3.42
12. Ability to Solve Traditional Descriptive Geometry Problems	2.29
2. Ability to Create Geometric Construction with Hand Tools	2.13

Table 2: Ranking of Performance Criteria for Outcome 1, Ability to Sketch in the Freehand Mode (Listed from Highest to Lowest Ranking).	
Performance Criteria	**Average Rank**
Demonstrate ability to make orthographic multi-view sketches	4.71
Demonstrate ability to make isometric sketches	4.54
Demonstrate ability to apply dimensions to freehand sketches	4.25
Demonstrate ability to make section view sketches	4.17
Demonstrate ability to make auxiliary view sketches	3.04
Demonstrate ability to do freehand lettering	2.79
Demonstrate ability to make oblique sketches	2.46
Demonstrate ability to make perspective sketches	2.38

Discussion and Conclusions

This paper presented a brief history of engineering graphical communication, leading up to the current position of 3-D solid modeling in engineering education. Results of a faculty survey on student outcomes indicate that new computer graphics tools and techniques are now the preferred mode of graphical communication. Long-standing techniques of Descriptive Geometry and manual geometric construction were soundly rejected in the survey. Nonetheless, it appears that engineering drawings are still a viable part of graphics instruction in engineering education, albeit the drawing should be projected from the 3-D model data rather than be constructed directly in 2-D.

Besides the dominance of computer modeling in the outcomes survey results, other more subtle conclusions can be made. Some traditional topics, like sketching, dimensioning, and sectioning, were ranked fairly high by the faculty. Thus, there is still a perception of the need for some graphics fundamentals in engineering education. There was also support for design projects and other team activities as part of graphics instruction.

In contrast, there was a surprisingly mediocre support for some of the exciting, advanced graphics topics like digital analysis, animation, and rapid prototyping. This suggests that faculty are uncertain about these computer graphics applications, although they realize the potential. It could also reflect a lack of these resources at some schools.

In response to the ABET criterion 3(g) calling for "effective communication" in engineering education, modern engineering graphical communication should focus on three areas of instruction, as shown in Table III. This trichotomy of instruction should include: *a*. computer modeling fundamentals; *b*. engineering graphics fundamentals; and *c*. computer graphics applications to digital analysis, manufacturing, animation presentations, and design projects.

Table 3: The Trichotomy of Modern Engineering Graphical
A. Computer Graphics Modeling Fundamentals
Creation of 3-D Computer Models
Creation of 2-D Computer Geometry
Building Computer Assembly Models
B. Engineering Graphics Fundamentals
Freehand Sketching
Generation of Engineering Drawings
Dimensioning
Sectioning
C. Computer Graphics Applications
Digital Analysis
Animation and Simulation Presentations
Rapid Prototyping and Manufacturing
Design Projects

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