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Engineering Graphics Concepts: A Delphi Study

Dr. Mary A. Sadowski, Purdue University, West Lafayette

Mary A. Sadowski has been at Purdue since 2003 and until September 1, 2011 served as the Associate Dean for Undergraduate Programs and Learning in the Purdue College of Technology where she provided leadership for strategic initiatives in undergraduate education.

As a professor of Computer Graphics, her research interests include enhancing visualization skills, creative thinking, and learning styles. She is currently funded to begin gathering data to create a concept inventory for engineering graphics. As a professor at both Purdue University and Arizona State University, Mary's specialty is computer and technical graphics. Dr. Sadowski received her B.S. from Bowling Green State University, her M.S. from The Ohio State University, and her Ph.D. from Purdue University.

Dr. Sheryl A. Sorby, Ohio State University

Dr. Sheryl Sorby is currently a Professor of STEM Education at The Ohio State University and was recently a Fulbright Scholar at the Dublin Institute of Technology in Dublin, Ireland. She is a professor emerita of Mechanical Engineering-Engineering Mechanics at Michigan Technological University and the PI or coPI on more than $9M in grant funding, most for educational projects. She is the former Associate Dean for Academic Programs in the College of Engineering at Michigan Tech and she served at the National Science Foundataion as a Program Director in the Division of Undrgraduate Education from January 2007 through August 2009. Prior to her appointment as Associate Dean, Dr. Sorby served as chair of the Engineering Fundamentals Department at Michigan Tech. In this capacity, she was responsible for the development and delivery of the newly adopted First Year Engineering Program at Michigan Tech. She received a BS in Civil Engineering, an MS in Engineering Mechanics, and a PhD in Mechanical Engineering-Engineering Mechanics, all from Michigan Tech. Dr. Sorby has a well-established research program in spatial visualization and is actively involved in the development of various educational programs.

Engineering Graphics Concepts: A Delphi Study

Abstract

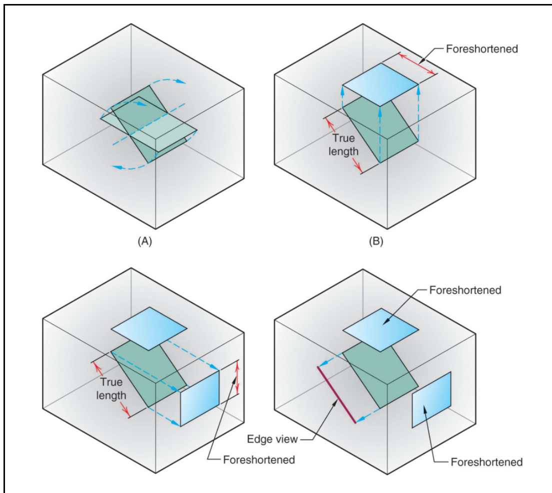
The Delphi technique is a consensus building, forecasting technique conducted via mail or Internet with a selected panel of experts, and in 2010 the authors were awarded a National Science Foundation grant to conduct a Delphi study to define the fundamental concepts of engineering graphics. The concepts determined through this study will be used to develop an Engineering Graphics Concept Inventory. A concept inventory is an instrument that can help faculty identify the concepts that their students do not understand and decide which misconceptions are the most prevalent. It can be used to help define important fundamental topics for instruction and learning. The Delphi technique typically encourages panelists to include comments as they make their ratings resulting in a rich written conversation about choices made, possible options, and changes that might be made in future rounds. The conversation, which is shared with all the participants, can help shape decisions made by other participants. This paper will focus on the results of the engineering graphics Delphi study that included graphic experts from universities, community colleges, high schools, and industry.

Introduction

Concept inventories can help define important fundamental topics for instruction and learning. A concept is an idea of something formed by mentally combining all its characteristics or particulars; a construct. A major aspect of this project has been to break engineering graphics into its many and varied constructs, to look at them individually, define them, and then bring some of them back together as unified concepts. The overall goal for this project is to develop an instrument which measures students' conceptual knowledge of graphic communication and enable faculty at all levels to assess student understanding of fundamental concepts in graphics, to evaluate the effectiveness of the courses they teach, and to make adjustments as necessary.(1) The purpose of the Delphi study was to define the important concepts that define engineering graphics.

Process

An initial brainstorming session with a small group of faculty leaders in graphics education was held in conjunction with the 66th Engineering Design Graphics MidYear Conference in Galveston, Texas. Topics in graphics education were listed and put into categories with no attempt to distinguish between "topics" and "fundamental concepts." The idea was to be as inclusive as possible with "weeding out" to be conducted in later stages of the Delphi study.[(2)] These brainstorming activities resulted in 80 graphic topics that were rated by the expert panel in the first of three rounds. Figure 1shows an example of the slides that were prepared for each topic that was rated. The use of graphics and verbal definition were used to ascertain that all of the panelists were working from the same vantage point. Rounds II and III further defined concepts that were considered critical for the discipline of engineering graphics. As consensus was achieved, some of the slides were dropped, others modified, and new ones were added.



Inclined Surface
An inclined surface is a plane surface perpendicular to one of the principle planes of projection.
An inclined surface is foreshortened in two of the principal views and a true length edge view in one view.

Inclined Surface image [(3)]

Figure 1. Sample Topic Slide from Round I

Comments from Expert Panelists

At each stage of the Delphi, panelists are given the opportunity to express their opinions, make suggestions for changes or deletions, or respond to a comment from the previous round. Panelists had the opportunity to see all of the comments, however, did not know who had made the comment. These comments sometimes offered a rich conversation about a concept that helped inform the panelists and the investigators. The investigators were able to use the comments to help guide the preparation of the next round.

As an example, Scales and Scaling were both presented in Round I and retained for Round II. Based on the comments and the scores from Round II, both Scales and Scaling were dropped;

however, Scale with the constructs of ratio and congruence were added for Round III. In this case the panel defined the concept; however, the final outcome was that Scale was not a critical concept of engineering graphics.

SCALES – comments after two rounds

- Ratios are a concept; scales are a tool for this.
- In a modern 3D parametric world we're not scaling drawing much, but the underlying concept of scale and its impact on the drawing is very important.
- Need an understanding of proportion and ratios more than actually being able to draw using a scale.
- Automatic in software. More important in some industries than others - such as civil, floor plan layout.
- While I am appalled that many studying engineering can't fathom the distance between a mile and a micron, the F for fit to screen key has reduced the need to teach scale in introductory courses.
- I go over the scales on a short-term basis.
- I feel this concept suffers by mixing two definitions of scale....scale as a tool, scale as a ratio. Ratio scale and concept of annotation scaling is different than a measuring device.
- Scales are primarily for measuring things on drawings. If the drawing is based on a computer model, the distances can/should be from the model. Lots of tools included in the software for measurements, etc.
- With computer graphics, instruction of scaling is done in viewport setup. Have not taught how to read a scale for years
- Diminishing in importance as more design documentation lives exclusively in electronic form.
- I think scale (1:4) is an important concept but not the tool scale any more.

SCALING – comments after two rounds

- Proportional control of a given shape is an important concept. Again capturing design intent and being able to reuse geometry.
- Students need to understand the drawing they are looking at may not be shown full scale. It is more important to size the views so they show information in a clear and precise manner. Normal ratios no longer matter either, 1:2 vs 1:2.5, since drawings are distorted when copied, scanned, faxed, etc. Standards need to stop using ratio and move to the scale system shown on maps.
- I give this one a lower rating only as just about every 3d printer, CNC code generator and any other post processing code has this function and it takes about 3 seconds to learn.
- This seems to be fading since there are few companies using hand drawings anymore.
- Was some of this concept represented in the scale as a tool and scale as a ratio?
- Nice to know. Not an essential starting point
- Definition is very explanatory and to the point
- Again as the scale of a drawing (1:4) but not as a modeling tool. What is the context?

As is apparent from the breadth and level of discourse surrounding the concept of Scales and Scaling, panelists were thoughtful in their responses. When items were recommended for elimination (or for maintenance), it was done through thoughtful consideration of the nuances involved and of the conversation that took place throughout the Delphi process.

Round II Results

The information from Round I was analyzed with 49 topics moving forward, 31 dropped, and 6 new topics added. Panelists were asked to review results, read the comments, and once again determine which were important concepts of engineering graphics. The data from Round II resulted in 12 larger concepts with 63 constructs or concepts within the larger topics. (Figure 2)

Visualizing in 2D	Edge View, Point View, Normal, Non-normal, Foreshortening, True Shape and True Size, View Alignment, and View Direction
Mapping between 2D and 3D	Conversion, Interpretation, Creation, and Criteria for Representation
Object Representation – Visual Depiction	Shape, Contour, Lighting, Outline, and Shading
Planar Graphical Elements	Reference Planes, Cutting Planes, Datum Planes, and Projection Planes
Sectional Views	Full Sections, Half Sections, Removed Sections, Revolved Sections, Offset Sections, and Broken-out Sections
Engineering Methodologies for Object Representation	Isometric, Oblique, Exploded, Perspective, Assembly, and Storyboards
Projection Theory	Line of Sight, Plane of Projection, Auxiliary Views, True Length, Edge View, Point View, and Inclined Surfaces
Parallel Projection Methodologies	Orthogonal, Axonometric, Oblique, and Isometric
Drawing Conventions	Annotations and Notes, Callouts, Concentricity, Labeling, Line Types, and Line Precedence
Dimensioning	Shape Description, Size Description, Dimension Placement, and Location Description
Solid Modeling Constructs	Extruding, Boolean, Lofting, Sweeping, Revolving, and Features
Scale and Similarity	Ratio and Congruence

Figure 2. Round II Results[4]

Round III Results

The data from Round III resulted in 10 major graphic concepts with 39 constructs/concepts within those major concept categories. These concepts will be used to develop an Engineering Graphics Concept Inventory, with a focus on concepts that are difficult for students to fully comprehend. The final concepts and constructs that were retained are listed in the order of importance as the panelists rated them. These ratings ranged from 4.3 to 4.8.

1. Visualizing in 2D (4.81): Understanding the relationship between orthogonal views of geometry.
   Edge View – Orthographically, an edge view is achieved when a plane surface is perpendicular to the plane on which it is projected.
   Normal – A plane perpendicular to the line of sight. Appears as a true length line or true shape plane.
   True Shape and Size – Features shown in an engineering drawing are true shape and size if the line of sight is perpendicular to the feature.
   View Alignment – Orthographic drawings are aligned horizontally and vertically. Every point or feature in one view must be aligned on a parallel projector in any adjacent view.
   View Direction – Arrangement of the principal orthographic views around the front view.

2. Sectional Views (4.63): Establishment of a plane for the purpose of showing interior and exterior features of an object.
   Full Section – Section view that shows the part cut entirely through, typically along the centerline.
   Half Section – View obtained when the cutting plane passes halfway through a symmetrical object to expose the interior of half of the object and the exterior of the other half.
   Removed Section – Used when only a partial section of a view is needed to expose the interior shapes.
   Revolved Section – View obtained when the shape of the cross section of a bar, arm, spoke or other elongated object is shown by revolving the feature.
   Offset Section – Used when sectioning irregular objects. The cutting plane is offset rather than straight allowing it to cut through and show different features of the object.
   Aligned Section – The cutting plane passes through angled arms, holes, or other features located around a central cylindrical shape and the section view is rotated into a single plane that shows features in the section true size.

3. Dimensioning (4.60): The process of providing an accurate, clear, complete, and readable, description of an object.
   Dimension Placement – Studied placement of size, location, and notes and symbols for the unambiguous description of geometry and process.

Location Description – Dimension that specifies the position of a geometric entity relative to another geometric entity.

Shape Description – Dimensions that define overall height, width, and depth of an object and its features.

Size Description – Dimensions used to describe the overall size as well as the size, width, and depth of object features.

4. Drawing Conventions (4.50): Conventional methods for expressing a graphical description.

   Annotations and Notes – Dimensions, tolerances, information, text, or symbols placed on an engineering drawing that give additional information to the reader.

   Callouts – Local notes that convey information about specific geometric features.

5. Planar Geometry (4.48): The ability to place a plane in space that serves a particular function.

   Cutting Plane – Imaginary plane which passes through an object, used to divide the object and reveal interior features.

   Datum Plane – Geometric reference point for parametric dimensions.

   Reference Plane – Used as a basis for measurement that locks the principle dimension of the object into a fixed relationship. The central view of a reference plane is perpendicular to the line of sight.

   Projection Plane – Representation of a line, figure, or solid on a given plane as it would be seen from a particular direction or in accordance with an accepted set of rules.

6. Projection Theory (4.47): Viewing an object with a transparent plane placed between the observer and the object.

   Auxiliary Views – Orthographic view of an object using a direction of sight other than one of the six basic views (front, top, right-side, rear, bottom, left-side); used to show a surface that is not parallel to any of the principal viewing planes.

   Edge View – Normal plane surface perpendicular to the plane on which it is projected and appears as an edge in two of the three orthogonal views.

   Line of Sight – Vector path from the viewer to a particular point on an object.

   Inclined Surface – Flat surface tilted at an angle with one end higher than the other, a plane whose angle to the horizontal is less than a right angle.

   Plane of Projection – View of an object that has been projected to a plane. In an orthographic drawing the top view is projected onto the horizontal plane, the side view on a profile plane.

   True Length – Perpendicular to the line of sight.

7. Mapping between 2D and 3D (4.45): Representing, converting, creating, and interpreting drawings from 2D to 3D and 3D to 2D.
   Interpretation – Reading and understanding standard information on an engineering drawing.
   Creation – Making 2D and 3D images using the appropriate tools.

8. Engineering Methodologies for Object Representation (4.29): Representing the 3D world using 2D visual methods using engineering graphic techniques.
   Assembly – Presentation of a product together, showing all parts in their operational positions.
   Exploded – View that shows an assembly's components separated and positioned to show the relationship or order of assembly of the parts.
   Isometric – Type of axonometric projection in which three of the axes are measured on the same scale and are at the same angle relative to each other.

9. Parallel Projection Methodologies (4.27): Graphically representing 3D objects in a 2D medium based on a line of sight and a plane of projection.
   Isometric – Type of axonometric projection in which three of the axes are measured on the same scale and are at the same angle relative to each other.
   Orthogonal – Two-dimensional graphic representation of an object formed by the perpendicular intersections of lines drawn from points on the object to a plane of projection.

10. Solid Modeling (4.27): A consistent set of principles for mathematical and computer modeling of three-dimensional solids which supports the creation, exchange, visualization, animation, interrogation, and annotation of digital models of physical objects.
   Extrusion – Normal profile can generate a solid of uniform cross-section by projecting it along a straight line with successive cross-sections all parallel.
   Features – Prominent region or portion of a part often associated with a particular function or geometric characteristic.
   Revolving – Operation whereby a generatrix rotates around an axis to define a surface. The revolution can be through any angular distance from 0 to 360 degrees.
   Sweeping – Operation that creates a solid body by extruding a 2D profile along a predefined path.

The data from the final round determined that two of the major concepts; Object Representation/Visual Depiction and Scale/Similarity did not warrant the same value as the other ten major concepts. Comments and ratings indicated that while there is value in both of these concepts, they are not fundamental to understanding engineering graphics. Within the remaining 10 major concepts a number of construct/concepts were also not moved forward or combined into other areas. These were: Axonometric Representation, Boolean Geometry, Concentricity, Congruence, Contour Object Representation, Conversion of Images, Criteria for Representation of Images, Labeling of Parts, Line Precedence, Line Types, Lighting, Object Shape Representation, Oblique Drawing, Perspective, Point View Geometry, Ratio, Shading, and Storyboards.

Final Survey

As a final step, the engineering graphics community was surveyed to determine which of the concepts from Round III should be considered for the concept inventory. Participants were asked to rate the difficulty a typical student might have understanding each of the concepts. Sixty-eight graphics professors, instructors, industry representatives, and teaching assistants participated in this survey. Figure 3 shows the results of this survey with 5.00 being the most difficult for students to understand. These ratings will be used to help determine which constructs need to be tested for the concept inventory. There isn't a clear break to distinguish which concepts were thought to be the most difficult to understand. Concepts that were rated below 3.2 will not be tested. Concepts in the 3.2 to 3.5 will be tested, however, with the understanding that many of these will not meet the difficult to understand standard that we are attempting to define. Test questions will be constructed for the concepts in the 3.2 and above range.

Aligned section	4.64
Revolved section	4.42
Auxiliary view	4.26
Offset section	4.23
Removed section	4.08
Interpreting 2D images	4.06
Projection plane	4.06
Creating 3D images	4.02
Dimension placement	4.02
Reference plane	3.95
Datum plane	3.93
Location description	3.82
Orthographic	3.79

True length	3.71
Cutting plane	3.70
Sweeping	3.70
Creating 2D images	3.69
Size description	3.68
Inclined surfaces	3.66
Shape description	3.66
Half section	3.61
Edge view	3.58
Plane of projection	3.51
View direction	3.49
True shape and size	3.43
Edge view	3.40

View alignment	3.37
Interpreting 3D images	3.33
Assembly	3.24
Isometric	3.16
Line of sight	3.13
Callouts	3.07
Revolving	2.98
Annotations & notes	2.97
Features	2.95
Exploded	2.90
Full section	2.87
Normal views	2.84
Extrusion	2.39

Figure 3. Final Survey Results

Summary

The purpose of this Delphi study was to determine the concepts that define engineering graphics and to further define which of these concepts give students the most difficulty. The panelists in this three-round Delphi study had the opportunity to accept, reject, and comment about the original 80 topics that were defined by a small focus group. After three rounds, the original topics coalesced into 10 major areas with 39 concepts within the major areas. The final step of this study was a survey to determine which of the 39 concepts were the most difficult for students to understand. The results of this study will be used to construct a concept inventory for Engineering Graphics.

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