Introductory Design Drawing for Technology Teachers

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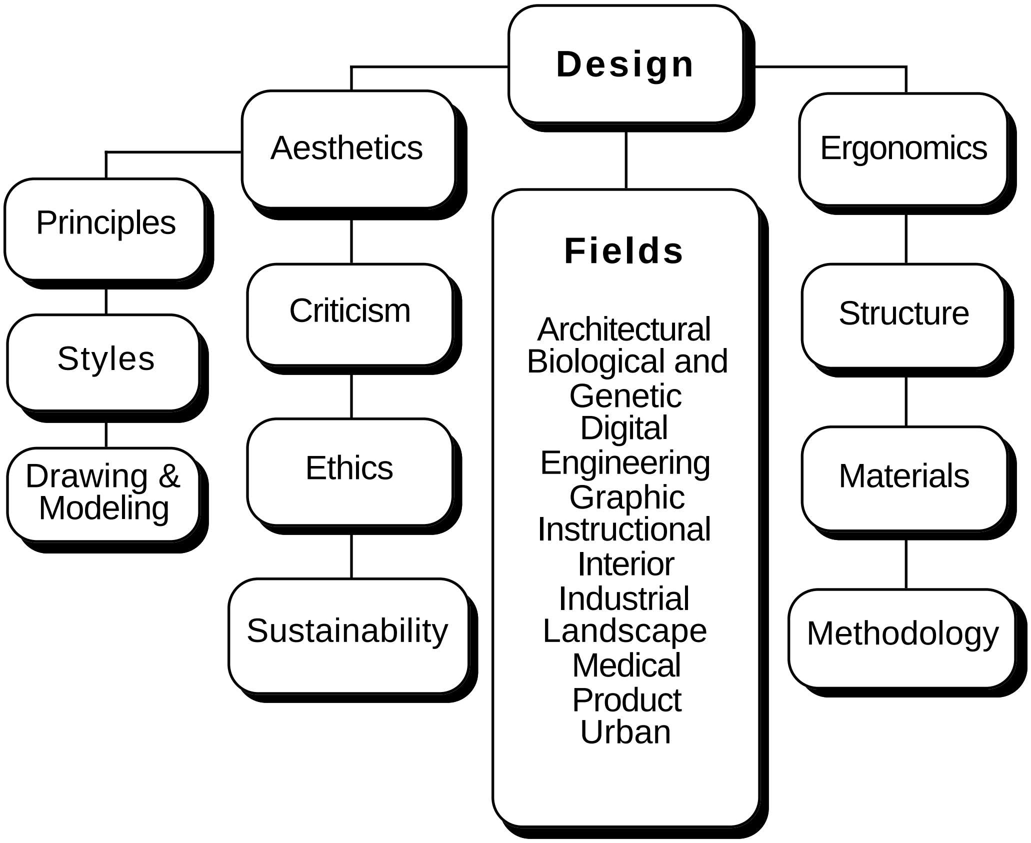

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Acknowledgements

This collection of resources was made possible through the interaction I had with countless students and teachers since the late 1970s. Their contributions to my appreciations, understandings and skills in design drawing are immeasurable. I have also benefited from the support of a number of universities, where the time to complete projects such as this was nade available to me. The editorial assistance of Shelagh Plenty, at the University of British Columbia, helped bring this project to a closure.

Introduction

I was taught engineering design drawing at my high school in the late 1970s and refined my drawing skills at California State University of Pennsylvania in the early 1980s. My first experiences with CAD were in the last year of my teacher-training program and in a one-week training workshop hosted by Intergraph in Pittsburgh during the winter of 1984. My experiences in teaching CAD date back to this same year, when I ordered two Macintosh 512 computers for the drafting course that I was teaching at Penn Cambria Senior High School in Pennsylvania. My students and I struggled along doing basic, two-dimensional (2D) drawings with MacDraw and MacDraft software applications. In 1987, I began graduate studies at the University of Maryland with a teaching assistantship and the charge of teaching beginning and advanced design drawing courses to industrial technology and teacher education students. By 1989 we were using AutoCAD Release 10 on IBM 286 PCs and in 1990 Auto CAD Release 11 on IBM 386 PCs in a laboratory of twenty machines. I grew skeptical of board drawing at this time. During one term I had a student who completed his board drawing assignments on his PC using AutoCAD and pencil-traced the hard copies to get credit for the board drafting assignments (He is now a designer for AutoDesk)! My instructorship at the University of Maryland ended after the spring term of 1992 and in the fall of 1993 I began teaching engineering graphics (i.e., drawing and CAD) at North Carolina State University (NCSU). I taught drawing and CAD through 1996.

The materials here were developed during this time. I wrote about these materials and experiences in an article titled "Two Cultures of Technical Courses and Discourses: The Case of Computer Aided Design," which can be downloaded from the Technology Studies Website at the University of British Columbia (www.cust.educ.ubc.ca/programs/tsed). I taught beginning drawing in the last few years at NC State by omitting the formal drawing aspects: We sketched and used CAD. We focused on drawing concepts, but sketched and used CAD to learn them. I adopted Dix and Riley's *Discovering AutoCAD Rel. 10* which allowed us to move beyond mechanical part reproduction. It is still published and is a great source of design problems that are not mechanical parts. Another excellent source and compendium for design drawing is Bertoline, Wiebe, Miller and Nasman's *Engineering Graphics Communication*.

The materials here include content outlines and the teaching materials I used. Basically, the materials are presented here in the order I presented them to the students. Start with pictorials—They are much more concrete than multiview drawings. Most, if not all, formal design drawing books insist on starting with multiviews. You will have much more success in visualization if you begin with sketching and pictorials. To board draw or not to board draw is a tough decision. I recommend daily sketching and CAD for good health. Good luck in your endeavors!

Points of Emphasis for Design Drawing

Basic Concepts- Students should understand/comprehend the following:

1. Geometric concepts basic to design graphics and CAD
2. Pictorials
    a. Axonometric projection
    b. Isometric
    c. Oblique
    d. Perspective
3. Multiviews (orthographic projection)
    a. Principal views, Sectional views, Auxiliary views
    b. Dimensioning theory, logic and convention
    c. Principles of true surface projection, foreshortening, distortion
4. Relationships between real space (3D), scale, and representational detail (2D Paper space)
5. Fundamental graphic representation and presentation
6. Role of graphics in a design context
7. Social and cultural implications of graphics and design

Points of Emphasis:

- Representation of complex three-dimensional objects and spaces on two-dimensional surfaces.
- Ability to visualize and move with confidence between real objects, visualized images (object space) and their two-dimensional representation (paper space).
- Ability to make and justify decisions related to layout, representation and presentation of objects.

Basic Technical Skills- Students should develop and refine skills in the following areas:

Sketching and Instrument Drawing

1. Basic Sketching
    - Elements— Metric (lines, circles, planes, discs), Stereometric (prisms, cones, spheres)
    - Shading
2. Basic instrument use
    - Technical pencil use, Lead selection
    - Lettering
    - Drawing paper layout w/title block, borders, objects
    - Engineering (Metric) scale use and scaling

Computer Aided Design

3. Simple configuration of CAD system for custom use
4. Organization and management of CAD system data
5. Creation, editing and deletion of complex 2D geometric data
6. Creation, editing and deletion of simple 3D geometric data

7. Storage and retrieval of data
8. Manipulation of data with peripheral devices including printers

Basic Abilities- Students should have the knowledge and ability to:
1. Apply and transfer basic concepts to real-world design graphics situations
2. Represent, in scale, complex 3D details in orthographic and simple objects in pictorial
3. Apply ANSI symbols where and when appropriate
4. Notate dimensions with respect to ANSI conventions
5. Produce drawings which represent exterior and interior (hidden) shapes
6. Produce professional looking, comprehensive, conventional detail drawings
7. Produce professional looking, simple assembly and working drawings
8. Produce drawings based on as-built or new designs with CAD

Points of Emphasis:

- Ability to comprehensively and conventionally represent objects for the purposes of production (i.e., details + assembly= simple to intermediate working drawings).
- Ability to read and evaluate detail drawings with confidence.
- Ability to clearly articulate a design rationale for CAD.

Upon completing introductory design drawing courses, the student should be able to:

1. Create graphic representations of problems commonly found in design using computer-aided design software.
2. Communicate the relative size and shape of surfaces as well as solids through multiview and pictorial representation.
3. Accurately describe the size and shape of an object using the principles of projection.
4. Mentally visualize the shape of 3D objects through graphical techniques.
5. Apply commonly accepted, conventional practices and standards to the graphic solutions to problems.
6. Describe the basic computer graphics concepts underlying the software tools used in CAD.
7. Understand the basics of using computer-aided graphic representations of designs in processes common to the design profession.
8. Integrate basic design graphics, concepts and skills to a project relevant to the field of design.
9. Articulate basic ethical and cultural issues of design drawing.

Content Outlines

Outline 1— Teaching CAD: Technical Approach

Drafting:

I. Basic Concepts
    A. Principles of Design
    B. Design drawing
    C. Visualization
II. Detail/documentation drawings
    A. Shape description
    B. Figured dimensions
    C. Specifications
    D. Title block
    E. Conventions
III. Auxiliary views
    A. Primary
    B. Secondary
IV. Assembly drawings
    A. Types
    B. Conventions
V. Working drawings
    A. Details
    B. Assembly
    C. Bill of Materials
    D. Conventions
VI. Tolerances
    A. Production dims
    B. Conventions
VII. Engineered fits
    A. Types
    B. Conventions
VIII. Threaded fasteners
    A. Styles
    B. Conventions
IX. Welds
    A. Types
    B. Conventions
X. Geometric Dimensioning and Tolerancing

CAD:

I. Introduction
    A. Overview
    B. Components of CAD system
        1. Hardware
        2. Software
    C. DOS
    D. CAD user skills
    E. Data storage
    F. Data handling
II. AutoCAD
    A. Main menu
        1. Drawing editor
        2. Configuration
        3. Plotting
    B. Commands
        1. Drawing
        2. Tool
        3. Edit
        4. Set-up
        5. Block and Attribute
    C. Prototype drawings
    D. Simple geometric shapes
        1. Entity creation
        2. Plotting
III. 2D drafting
    A. Layers
    B. Dims
    C. Plotting with layers
IV. 3D modeling
    A. Wireframe
    B. Surfaces

Outline 2— Teaching CAD: Social and Technical Approach

- I. Introduction
  - A. CAD
    - 1. Principles of Design
    - 2. Design Drawing
    - 3. Visualization
  - B. Components of CAD systems
    - 1. Hardware
    - 2. Software
  - C. Operating Systems
  - D. CAD user skills
  - E. Data storage
  - F. Data handling
- II. CAD system interface
  - A. Main menu
    - 1. Drawing editor
    - 2. Configuration
    - 3. Plotting
  - B. Commands
    - 1. Drawing
    - 2. Tool
    - 3. Edit
    - 4. Set-up
    - 5. Block and Attribute
  - C. Prototype drawings
  - D. Simple geometric shapes
    - 1. Entity creation
    - 2. Plotting
  - E. 2D CAD
    - 1. Layers
    - 2. Dims
    - 3. Plotting with layers
- III. Symbol libraries
  - A. Access
  - B. Organization
  - C. Slides
- IV. Databases
  - A. Integration
  - B. Dbase
- V. 3D modeling
  - A. Wireframes
  - B. Extrusions
  - C. Surfaces/ Meshes
  - D. Solids
- VI. Design and Analysis

- I. Implications of CAD
  - A. Social
  - B. Psychological
  - C. Organizational
- II. Education
  - A. Motivation
  - B. Potential
  - C. Learning Strategies
- III. History of CAD
  - A. Invention
  - B. Development
  - C. Innovation
  - D. Momentum
- IV. Support for Users
  - A. Journals
  - B. User Groups
  - C. Database services
- V. Consumer Decision Making
  - A. Criteria
  - B. Information
- VI. Organizational Decisions
  - A. Market Trends
  - B. Projected Opportunities
  - C. Employment
  - D. Managing Innovation
- VII. Research
  - A. State-of-the-Art
  - B. Needs
- VIII. Potential
  - A. Productivity
  - B. Overkill
- IX. Creativity
- X. Speculation
  - A. 1995
  - B. 2000

Outline 3— Teaching CAD: Sociotechnical Approach

- I. Introduction
    - A. CAD
    - B. Components of CAD systems
        - 1. Hardware
        - 2. Software
    - C. Operating Systems
    - D. CAD user skills
    - E. Data storage
    - F. Data handling
- II. CAD system interface
    - A. Main menu
        - 1. Drawing editor
        - 2. Configuration
        - 3. Plotting
    - B. Commands
        - 1. Drawing
        - 2. Tool
        - 3. Edit
        - 4. Set-up
        - 5. Block and Attribute
    - C. Prototype drawings
    - D. Simple geometric shapes
        - 1. Entity creation
        - 2. Plotting
    - E. 2D CAD
        - 1. Layers
        - 2. Dims
        - 3. Plotting with layers
- III. Symbol libraries
    - A. Access
    - B. Organization
    - C. Slides
- IV. Databases
    - A. Integration
    - B. Dbase
- V. 3D modeling
    - A. Wireframes
    - B. Extrusions
    - C. Surfaces/ Meshes
    - D. Solids
- VI. Design and Analysis

- I. Product and Service Life Cycles
    - A. Designing, Engineering and Planning
        - 1. Data management
        - 2. CAD and DTP
        - 3. Parts Acquisition
        - 4. Concurrent Engineering Design
    - B. Developing and Testing
    - C. Producing
    - D. Reintegrating, Reconceptualising, Recycling
    - E. Constructive Technology Assessment
- II. Economy, Workforce and Workplace
    - A. Workplaces (Structure, Tasks, Culture)
    - B. Market Trends and Forces
    - C. Opportunities
        - 1. Worker Well-being
        - 2. Creativity and Productivity
        - 3. Labor and Management
- III. Technology, People and Management
    - A. Innovation in the Factory and Office
    - B. Computers and Automation
    - C. Managerial Innovation
    - D. Organizational Structures
- IV. Managerial, User and Consumer Decision Making
    - A. Forecasted Information
    - B. Empirical Information
    - C. Experience
    - D. Continuing Education and Training
- V. Sociotechnical Theory
    - A. Sociotechnology and Workplaces
    - B. History of CAD in Workplaces
    - C. Sociology of CAD
    - D. Psychology of CAD

Outline 4— Teaching CAD: Technical Approach (CAD w/Drawing)

- I. Engineering Graphics and CAD
    - A. Design and Communication
        - 1. The design process
        - 2. Product life cycle
        - 3. Concurrent engineering
        - 4. Parametric design
        - 5. Principle of Design
        - 6. Visualization
    - B. Social and Cultural dimensions
    - C. The values
        - 1. Neatness and clarity
        - 2. Accuracy
        - 3. Standardization
        - 4. Comprehensiveness
        - 5. Speed
- III. Sketching and Visualization
    - A. Tools
    - B. Shape description in a 3D world
    - C. Pictorials
        - 1. Oblique
        - 2. Isometric
        - 3. Perspective
    - D. Multiview
    - E. Plans and elevations
    - F. Surface description
    - G. Figured dimensions
- IV. Engineering Geometry and Construction
    - A. Simple 2D geometry
    - B. Representation of 3D forms and shapes
- V. Computer-Aided Design (CAD)
    - A. Hardware and peripherals
    - B. Software
    - C. Systems software
    - C. Data Handling
    - D. Data storage
    - E. Configuration
- VI. CAD user skills
    - A. Drawing editor, set up and tools
    - B. Configuration
    - C. Output
    - D. Prototypes
- VII. Entity creation
    - A. Simple 2D geometry
    - B. Text
    - C. Blocks
    - D. Simple 3D modeling
        - 1. World coordinate system
        - 2. Wireframes
        - 3. Extrusions
        - 4. Surfaces/ Meshes
        - 5. Solids
- VIII. Formal drawing theory and application
    - A. Parallel projection
    - B. Drawing styles and rationales
    - C. Conventions and standards
- IX. Multiview drawing
    - A. Principal views
        - 1. Surface description
        - 2. Size
        - 3. Position/ Location
    - B. Sectional views
    - C. Auxiliary views
- X. Dimensioning
    - A. Dimensioning theory & logic
    - B. Symbology & standards
    - B. Production dimensioning and tolerancing
- XI. Manufacturing Processes
    - A. Engineered fits
    - B. GDT
    - C. Threaded fasteners
    - D. Welds
    - E. Machine processes
- XII. Detail and documentation drawing
    - A. Shape description
    - B. Figured dimensions
    - C. Tolerances and specifications
    - D. Title block
- XIII. Working drawings
    - A. Detail drawings
    - B. Assembly drawings
    - C. Bill of Materials

Design Drawing Theory

Basic Concepts

Surface descriptions:

- Plane
- Normal
- Regular
- Inclined
- Curved
  - Conical
  - Cylindrical
  - Spherical
  - Elliptical
- Warped
- Inclined
- Oblique
- Foreshortening
- Distortion

Views:

- Principal
- Auxiliary
- Sectional
- Edge
- Contour
- Point
- Plan
- Elevation
- Section
- Profile
- Frontal
- Horizontal

Shape description:

- True shape
- Distorted

Projection theory:

- Parallel
- Perpendicular
- Oblique
- Perspective

Representational styles:

- Orthographic
  - Multiview
- Oblique
- Axonometric
- Perspective

Drawing technique:

- Point transfer
- Projection

Dimensioning theory:

- Size
- Location
- Position
- Distance
- Length
- Height
- Depth
- Point to point
- Surface to point

Industrial processes:

- Production
- Fabrication
- Drilling
- Welding
- Boring
- Fastening

S. Petrina. (2003). *Introductory design drawing for technology teachers*. Vancouver: Tech no-Printing Press.

*The proceeding sections on theory are excerpted and summarized from:
Muller, Edward J. (1976). *Architectural drawing and light construction*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Sketching

Sketching is a natural means of expressing ideas. Especially in the initial stages of creative work, the designer uses sketching in its various forms as freely as s/he writes or records other languages with a pencil. The graphic language, supplemented by written language, conveys an idea very rapidly, completely, and accurately. A knowledge of the techniques of freehand sketching has become an essential criterion of a successful architect, designer or technologist.

The arrangement and appearance of drawings are essentially the same in both instrumental and freehand drawing; the theory of projection is identical. Much of the theory of technical drawing and projection can be learned as the student develops her or his sketching techniques. Since the difference between instrumental drawing, computer-aided design (CAD) and sketching is a matter of refinement of lines and not of theory, the designer must be well versed in the theory of projections and conventional practices of design graphics.

In order to execute a freehand sketch, the only requirements are a pencil, a piece of paper, and the idea to be sketched. Instruments, other then the F pencil, are cumbersome objects that usurp time and frequently become obstacles in a developing idea. The beginning student should never lose sight of the fact that s/he must become as fluent in sketching as in their present handwriting. Scales, compasses, and other instruments are a temptation during the initial training period, but are a detriment to the student's development into a productive designer.

A freehand line will differ naturally in appearance from a mechanically drawn line. This difference should be only the reflection of the human touch. The sketched lines should be as nearly as possible identical to those drawn instrumentally. There are only two shades of lines: very light (construction lines) and dense (all other lines). An F pencil is very excellent for sketching; it allows erasures to be made easily, but is not so soft as to cause excessive smudging. An HB pencil has a good feel, but can get a bit smudged if not careful. There are three thicknesses of sketched lines. Freehand lines and mechanical lines should be comparable in this respect also. Visible object lines are thick, invisible object or hidden lines are medium, and all other lines are thin lines.

Many sketching techniques have been developed by designers and engineers. As the student becomes more proficient in the use of the graphic language s/he too will develop their own style which will vary slightly with the style of their classmates. Some practices have been found very successful throughout the years and should be given a fair trial period before the novice attempts to develop their own technique.

In sketching, the paper is usually free to be shifted to any angle. Long lines are easier to keep straight when drawn as horizontal lines to correspond to the left to right arm movement and the paper may be positioned to accommodate the movement of the forearm. For short lines, shifting the paper may be more cumbersome than making strokes in other directions. Whenever a straight line is sketched, the end points of the line should be sighted and even marked if preferred. Using very light, short, and snappy strokes, a construction line should be drawn between the points. The finished line should be drawn correcting the imperfections of the construction line and brightening the line to a black line of the thickness required.

Circles may be sketched several ways. Small circles can be formed easily by constructing a square whose distance along each side is the approximate diameter of the circle and inscribing the circle. Larger circles may be done by the marking of little arcs equal to the approximate radius along each portion of the center lines. Additional diagonal lines through the crossed center lines, with the radial distance marked, is helpful as the size increases. The space between the arcs is lightly sketched to complete the circle, then brightened.

Al though the use of a scale is not advisable in the process of sketching, the proportional measurements of the object are important in producing a meaningful sketch. The problem becomes one of judging proportions. Is the height one and one-half times the depth, etc.? Each feature of the object must be judged to determine its proportionate size.

Projections

A projection is the image created on a projection plane by "lines of sight" from the observer's eye to the object. The student may have frequently looked out the window at a house across the street. Lines of sight from the student's eye to the various points on the building allow them to see the building. The lines of sight diverge or spread as they project from the student's eye through the window glass to the house across the street. Imagine that the window glass is the plane of projection and that the student traced on the glass the exact outline of the house s/he saw across the street. The projection of the house is much smaller than the house itself. Also, any portion of the house that is farther away than the front projects proportionately smaller than the front of the house. The farther away an object is from the plane of projection the smaller will be the projection on the projection plane which lies between the eye and the object. This is because all of the lines of sight originate at one point— the eye. Only those lines or surfaces that lie in the plane of projection remain true length in the projection. Whenever the observer views an object from a finite position, the projection will have the characteristics described and is known as a perspective.

Since it is impossible to have all of the lines and surfaces of a three-dimensional object lying in the plane of projection, a perspective of the object would have many lines that were not true size. The designer most frequently uses a system of projection that eliminates the size deviations which result from perspective projection. If the observer moves back from the projection plane the lines of sight to the various points on the object come close to becoming parallel to one another. When the observer is at an infinite distance from the plane of projection the lines of sight theoretically become parallel. Thus, we have the basis for the system of projection known as parallel projection. Orthographic projection is a form of parallel projection in which the lines of sight are always perpendicular to the plane of projection. The different forms of orthographic projection therefore, depend upon the positioning of the object and the observer in relation to the plane or planes of projection. Multiview projection is the most frequently used system of projection in graphic analysis. The system uses more than one plane of projection through which to view the object. Each projection is known as a view of the object. The three principal views used are the front, top, and right side. The front view shows the width and height of an object. The top view shows the width and depth, and the right side view shows the height and depth. So far in our study, it is apparent that any single view of an object describes accurately two dimensions only. It is therefore, obvious that no three-dimensional object can be described thoroughly by only one of the multiple views. Figure 1 shows the principal types of projection and their relationship to each other. All of the types listed have not been mentioned in this discussion of projections. We will merely recognize their existence now and discuss them more thoroughly later in our study of graphic analysis.

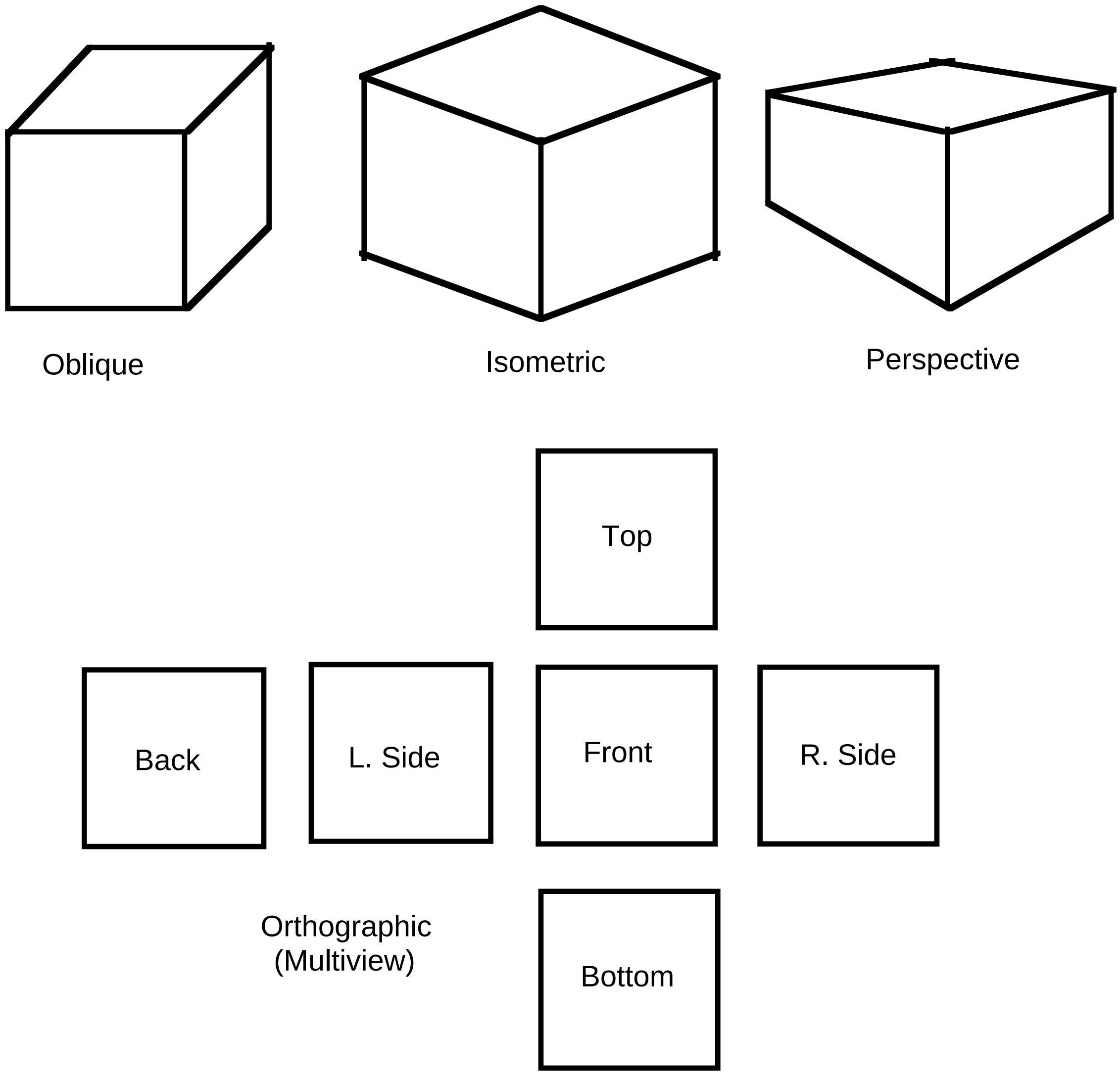


Figure 1. Types of Projections

Multiview Projection

Multiview projection is a type of parallel, orthographic projection. It is a system by which an object may be described completely through the use of two or more orthographic projections, each of which is a two-dimensional view of the object. A systematic arrangement of the views assures completeness in presentation and ease in reading. The principal views of the object are those which are viewed through planes of projection which are mutually perpendicular to each other. The object usually is positioned so that its characteristic shape is shown in the front view. In some instances the natural position of usage is given preference. Views which are placed adjacent to the front view are the top, right side, left side, and bottom views. Each of these projections is viewed perpendicularly to the front view.   When used, the back view is conventionally placed on the paper adjacent to one of the side views.

Multiview projection and the placement of the various views on paper are derived directly from a glass box concept. The student may imagine a hollow box, whose sides are sheets of glass, with a rectangular object placed inside with each of its six faces parallel to the six glass surfaces of the box. Each face of the glass box would represent a plane of projection. Through the front plane of projection, the front of the object would be seen. The width and height of the object are shown in the front view. The observer may then change positions to view the object through the top horizontal plane of projection. From this position s/he would see the projection of the top of the object if s/he also can see the width and depth of the object. Similarly, the observer can view the object through the remaining four planes of projection. But in order for the views obtained to be useful, the observer must place each projection obtained on paper. To place them on paper, s/he imagines that the edges of the glass box are hinge lines. The edge between the front pane of glass and the top pane of glass is the hinge that allows the top plane of projection to be rotated into the same plane as the front projection plane. Hence, the top view is directly above the front view. These views will align the: common dimension, width. In similar fashion the other four planes are revolved into the front plane in order to place them on paper.

Al though the glass box has six planes, it is possible to think of it as having only three kinds because there are three sets of parallel planes. Since the three kinds of planes are mutually perpendicular, all three dimensions of an object (height, width, and depth) are represented. The top and bottom views therefore, may convey the same information. Likewise the right side and left side views or the front and back views may be repetitious. In most cases, three views convey all of the information to adequately describe an object. The three views are usually the front, top, and right side. The three kinds of projection planes upon which the views are projected are known as the frontal, horizontal, and profile planes

The intersection of the frontal and horizontal planes of projection create four quadrants into which an object may be placed and viewed (Figure 2). The first and third angles are both used extensively: throughout the world. When the first quadrant is used, the lines of sight travel from the observer's eye to the object and then to the plane of projection. When the third angle of projection is used, the lines of sight travel from the observer's eye through the plane of projection to the object. The views obtained by the two systems are identical, but they are hinged into different relative positions on the paper. In first angle projection the top view is placed below the front view on the drawing and in third angle projection, it is placed above the front view. In

Canada and the United States the third angle of projection is used and we will conform all further discussion of multiview drawing to this system.

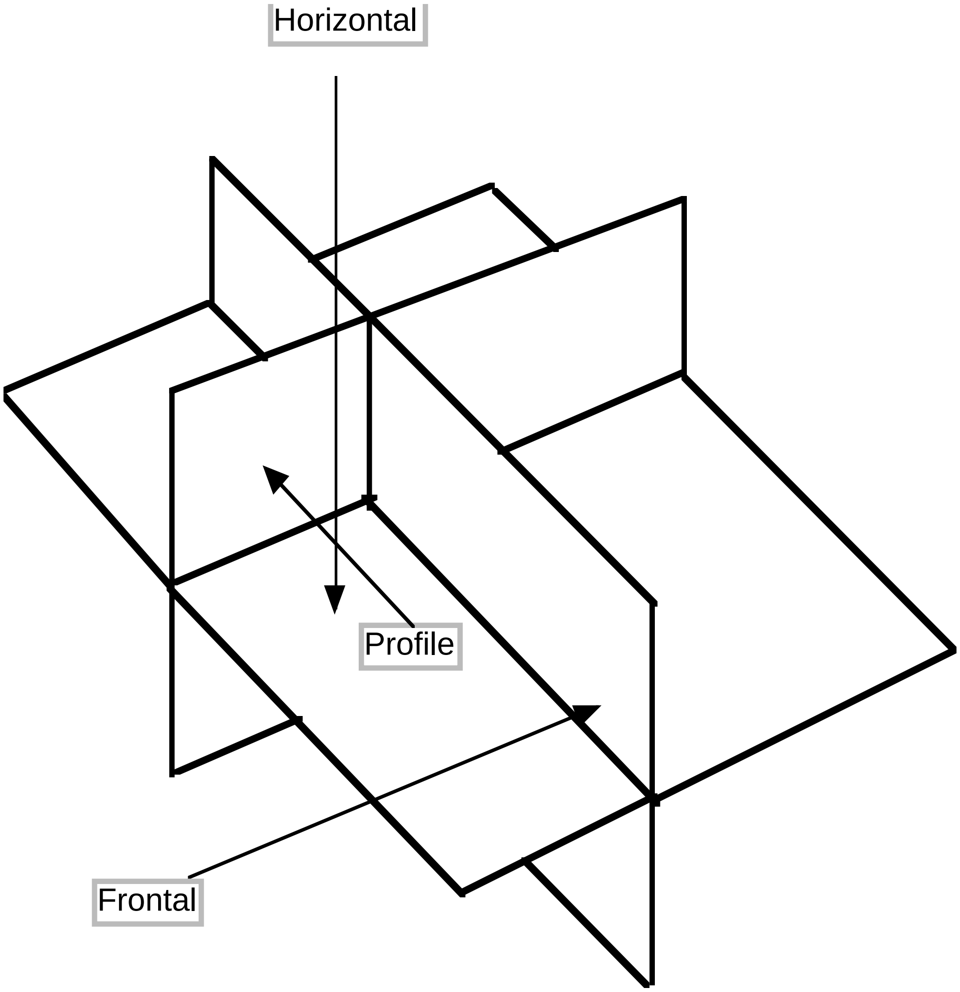


Figure 2. Planes of Projection

The representation of the object which appears on the plane of projection is comprised of lines. A line may represent an intersection of surfaces, a plane as an edge, or a limiting element of a curved surface. Frequently, a line represents more than one thing at a time. As a case in point, it may represent an intersection of surfaces and a plane as an edge. Because the lines of sight are parallel and perpendicular to the plane of projection in orthographic projection, straight lines will project true length, foreshortened, or as a point. Never can a line project longer than its true size in multiview projection.

The lines which form the view of an object create areas on the drawing. These areas represent surfaces of the object or open spaces where the object does not exist. Such areas may represent the true shape of a surface, an inclined surface, a curved surface or tangent surfaces. Plane surfaces will project true size and shape, foreshortened or as an edge. Since lines and the surface they bound are the basis of every graphical view of an object we will turn to a more detailed examination of lines and planes.

Points, Lines and Planes

Lines are frequently described as an infinite number of points lying side by side. Plane surfaces are bound by lines which are comprised of points. It is to our advantage, therefore, to take a closer look at points in orthographic or multiview projection so that we may understand the projection of the foundational unit of an object in space.

A point is a theoretical entity; it has no dimensions. On paper we must represent points by dots or cross marks which have size. It is important that the student recognize that this representation is inaccurate and that the point represented is an infinitesimally small entity at the center of the representation. A line, surface, or solid object may be considered to be comprised of an infinite quantity of points properly placed in space. Let us see how these points are viewed in orthographic projection.

In our discussion of multiview projection, it was stated that the frontal and horizontal planes of projection were perpendicular to each other. Using the line of intersection of the two projection planes as a hinge, the top view is swung directly above the front view. Frequently the folding line between the views is drawn on the paper. Above the folding line an H may be lettered indicating that in the top view the horizontal plane of projection is true size. For the top view, the folding line represents the frontal plane of projection as an edge. Below the folding line the letter F may be used to indicate that in the front view the frontal projection plane is true size. For the front view the H-F folding line represents the horizontal plane of projection as an edge. Similarly, a folding line between the front and right side views may be drawn and labeled F-R. The folding line between any two views reminds the reader that the two views are perpendicular to each other and that the folding line represents one of the two planes of projection as an edge in each view.

Views which share a folding line are known as *adjacent views*. They are placed next to each other and align their common dimension. Normally, the top and front views are adjacent to each other and share the common dimension of width. The student should be able to list all other views that are adjacent to the front view and list the common dimension each has with the front view. When the lines of sight to any point on an object are projected onto the complementary plane of projection, they form straight lines perpendicular to the folding line. Thus any one point must lie along a projector that is perpendicular to the folding line two adjacent views.

Two or more views that are adjacent to the same view are known as related views. The top view, for example, is related to every other view that is adjacent to the front view. Related views acquired their name because of a definite space relationship between them. They are all formed on planes which are perpendicular to the same plane while the projection is formed. Consequently, the perpendicular distance from the common projected plane to a particular point on the object will be parallel to each of the perpendicular planes. In the actual mechanics of putting their ideas on paper, designers know that a point that is shown in the front and right side views may also be projected along a line perpendicular to the H-F folding line and will be located the same distance from the H-F folding line in the top view as it is from the F-R folding line in the right side view.

If a point is located in two adjacent or two related views the point is then established in space. The point can be plotted in all other views. Frequently, the solution of space problems must be found by methodically plotting points between adjacent or related views. Sometimes it may be difficult to visualize how an object will project. Points must be plotted and visibility determined through the principles of multiview projection.

Visibility of an object may be determined easily by applying a few simple rules.
Rule 1: All outside lines of the object must be visible. No matter how an object might be tilted to the plane of projection, the extremities of the object are visible.
Rule 2. When lines cross each other in one view, the adjacent view will show whether or not they intersect or cross at that particular point. If they cross, the visible one will be the one that is closest to the folding line in the adjacent view along the line of sight.
Rule 3: The principal of using adjacent views for visibility of lines that cross will also apply to a line and surface or two surfaces. The student must ask, "What can hide this line, or point, or surface?" Then s/he must look in the adjacent view to see whether the specific thing that could hide the item actually does or does not. If the item is hidden, it must be farther away from the folding line than the item that shields it from the eye.

Spatial relationships of lines and planes are seen in multiview projection by having the observer view the object from several directions. Multiview projection succinctly describes an object and the reader must study reflectively the various aspects of the object. Such an analysis requires a thorough knowledge of lines and planes and their patterns of space occupancy.

There are three kinds of **lines**: *normal, inclined, and oblique*. Normal lines are parallel to two of the principal planes of projection and perpendicular to the other. The true length of a normal line will be seen on the two planes to which it is parallel and will be seen as a point on the other. Inclined lines are parallel to one of the principal planes of projection and inclined to the other two. One principal view will show the true length of an inclined line and the other two views will show foreshortened line which lies parallel to the folding line. Oblique lines are inclined to all three principal planes of projection and project foreshortened on each.

When a line lies parallel to a plane of projection, it projects as a *true length* line on that plane. Lines that project in true length on the horizontal plane are known as horizontal lines and those which project as true length lines on the profile plane are profile lines.

The direction of a line may be determined if two adjacent related views of the line are shown. Any two points on the line may be observed. In the top view one point will show in front of, behind, or in the same frontal plane as the other. It will all show to the left, right, or in the same profile plane as the other. Likewise, information concerning the direction of the line may be determined in the front view. One point will project to the left, right, or in the same profile plane as the other point; also it will project above, below, or in the same horizontal plane as the other and it will project in front of, behind, or in the same frontal plane as the other.

When the observer is looking at the frontal plane of projection, the H-P folding line actually represents the horizontal plane of projection as an edge. Therefore, any line that projects parallel to the H-P folding line in the front view will project true length in the top view. This is true for all adjacent views. All views adjacent to the view in which a line shows true length will have that line project parallel to the folding line.

There are three kinds of **planes**: *normal, inclined, and oblique*. A normal plane is one that is parallel to one principal plane of projection and projects in true size and shape on this plane. It is perpendicular to the other two planes of projection and projects as an edge parallel to the folding line in these views. An inclined plane is one that is perpendicular to one principal plane of projection and inclined to the other two. A plane that is inclined to all three of the principal planes of projection is known as an oblique plane.

Normal and inclined planes can be more thoroughly classified depending upon how they project in a particular view. A normal plane that has its true size and shape shown on the horizontal projection plane is known as a horizontal plane. Likewise, one which projects its true size and shape on a frontal or on a profile plane of projection is known as a frontal or profile plane respectively. A plane that projects as an edge on the frontal projection plane is known as an edge-frontal plane. An edge-horizontal plane is one that is perpendicular to the horizontal plane and an edge-profile plane is perpendicular to the profile plane of projection.

The direction of a plane is the way the plane slopes and is usually expressed in a downward direction. It may be determined by viewing a horizontal line on the plane in the top view and observing the direction of a line perpendicular to the true length horizontal line. If the perpendicular line is drawn on the same side of the horizontal line as the lowest point on the plane in this view, it points in the direction that the plane slopes downward. The lowest point on the plane can be determined by observing any elevation view. When determining the direction of the plane in the top view, the perpendicular line to the horizontal line would represent the path along which a ball would roll if released on the horizontal line. If, for example, the perpendicular line goes back to the right, the plane slopes down-right-back.

Auxiliary Views

An auxiliary view is one which is projected on any projection plane other than one of the three principal planes of projection (Figure 3). The projection of auxiliary views is an integral part of multiview projection. In our previous discussions on multiview projection, the observer viewed the object from infinity through the frontal, horizontal, or profile planes of projection. The concept of multiview projection is expanded through the use of auxiliary views from the exclusive use of three mutually perpendicular projection planes to the use of an additional infinite number of planes of projection to supplement the principal three.

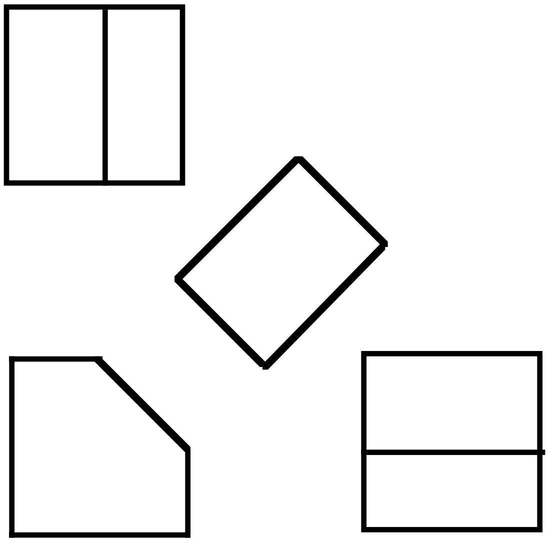


Figure 3. Primary Auxiliary View from Inclined Surface

Sections and Conventions

A sectional view is an orthographic projection of an object showing the object as it would appear if it were cut open. Sectional views are used to describe objects that would be difficult to visualize in a regular projection using hidden lines. The portion of the object that has been theoretically cut by a cutting plane is shown by section lines or crosshatching. The section lines clearly define the internal structure of the object (Figure 4).

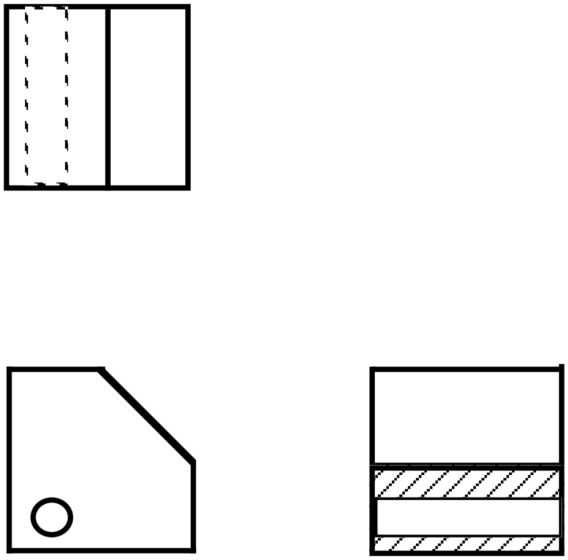


Figure 4. Sectional View

Pictorial Drawings

The accurate presentation of multiview projections has the disadvantage of being somewhat abstract. The human being is accustomed to seeing things in three dimensions. The two dimensional views of objects in multiview projection must be integrated by the reader to form mentally the concretion which it represents. Frequently pictorial drawings or projections are used to supplement a group of multiview drawings. Pictorial illustrations of technical material are used as guides for assembly work, as illustrations in catalogs and handbooks, as schematic layouts, as illustrations of multiview projections, or as manufacturing prints of less complicated objects. Any three dimensional projection of an object is known as a pictorial drawing; however, several methods of projection are used extensively to obtain a three-dimensional view. We will now discuss the remainder of the types of projection which were illustrated in Figure 1.

Oblique Projections

Oblique projection is a branch of parallel projection in which the lines of sight are oblique to the plane of projection. The image is formed on one of the three principal planes of projection usually the frontal plane. Since the lines of sight are parallel to each other, the two axes of the object which are parallel to the picture plane project in true length. Thus the image of any portion of the object which lies in a plane parallel to the plane of projection is true size and shape. Oblique projections are used extensively for objects which have curved and irregular surfaces which lie in parallel planes.

The length of the receding axis is dependent upon the angle the lines of sight make with the plane of projection. If the line of sight makes an angle of 45-degrees with the plane of projection, the receding axis will be true length. This is because the tangent of 45-degrees is one. Since the tangent is the opposite side over the adjacent side, the line of projection equals the length of the receding axis. If the angle that the lines of sight make with the plan of projection are smaller than 45 degrees, the projection of the receding axis will be longer than true length. The angle the projectors make with the plane of projection has no bearing on the angle of the receding axis on the drawing. The angle the projectors or lines of sight make with the plane of projection only governs the proportionate length of the receding axis. A line of sight projecting through any one point on the plane of projection could come from an infinite number of directions all making the same angle with the plane. It is the direction from which the lines of sight come that determines the angle of the receding axis on the drawing. In practice the receding axis is drawn usually as an angle of 30 or 45 degrees with the horizontal to correspond with standard drafting triangles.

When the lines of sight make an angle of 45 degrees with the picture plane, the image is known as a *cavalier projection*. Measurements parallel to all three axes are made in true length. Angles, circles and circular arcs which lie in planes parallel to the projection plane are true shape. If they lie in one of the receding planes, they must be located by the same type of offset methods used in isometric drawing. Circles and arcs that lie in a plane parallel to one formed by the receding axis and another axis, may be drawn by the four centre ellipse method. An oblique square is formed and the four centres are located where the perpendicular bisectors of the sides intersect.

A *cabinet projection* is formed by the lines of sight making a: angle of 63 26' with the plane of projection. Since the tangent of 63 26' is two, the opposite side (the true axis) is twice as large as the adjacent side (the projected axis). The receding axis: of a cabinet projection, therefore, is half size. Angles, circles and arc that lie in one of the receding planes must be located by offset methods because of the reduced scale used on the receding axis.

Normal Axonometric

Axonometric projection may be the projection onto a projection plane which is oblique to all three principal planes of projection. Thus each secondary auxiliary view may be considered a normal axonometric projection and a branch of multiview projection. Most frequently, however, the object is thought to be rotated behind a picture plane until all three axes of the object project onto the plane.

If the object is positioned behind the picture plane so that each of the three axes (height, width, and depth) make equal angles with the picture plane, the resulting projection is an *isometric projection*. The three axes project on the plane of projection as three foreshortened intersecting lines forming three equal sectors of 120 degrees. Each of the axes makes an angle of approximately 35 16' with the picture plane. Their projections on the picture plane is equal to the product of the cosine of 35 16' and their true length, which is approximately 81.6% of their true length. An isometric projection can be drawn directly by laying-out the three axes on the paper and making all measurements with an isometric scale. If a regular scale is used, the drawing produced is proportionally true, but larger than a true projection and is known as an isometric drawing.

All lines parallel to any of the three isometric axes are known as isometric lines. Isometric lines may be measured directly on the isometric projection or drawing. Non-isometric lines must be located by plotting distances of selected points in directions parallel to each of the axes. Most curves and irregular lines must be plotted by using the offset measurements from the coordinate axes. Circles that lie in an isometric plane may be drawn by first drawing an isometric square equal to the diameter of the circle. The centres of four arcs which form the approximate isometric ellipse are located where the perpendicular bisectors of the sides of the square cross.

If the object is positioned so that only two of the three axes make equal angles with the plane of projection, the picture obtained is a *dimetric projection*. The third axes may make larger or smaller angle. Dimetric projections may be obtained through auxiliary views or they may be drawn directly by using properly foreshortened scales along properly spaced axes. The various points of the object must be measured parallel to each of the axes using the proper scale. Slight adaptations of both angle and scales are often made to yield an approximate dimetric drawing.

A *trimetric projection* of an object is obtained by positioning the object so that all three axes make different angles with the plane of projection. Each of the axes of a trimetric projection is foreshortened by a different value and the angles formed by the axes vary. Obviously, there may be an infinite number of trimetric projections. This form of projection has had limited application in engineering fields.

Perspective

All of the forms of projection that we have discussed thus far have been branches of parallel projection. The observer has been looking at an object from an infinite distance so that his lines of sight are parallel. In perspective, all lines of sight diverge from one point. The observer is located at this finite position called the station point. Usually the picture plane is located between the station point and the object, causing the object to project smaller than true size.

In perspective, parallel lines that do not lie parallel to the picture plane converge to a point. If the student will recall looking down a street lined with telephone poles, the poles farther away appear smaller and the wires seem to be converging. The distant objects appear smaller than the objects near the observer because the lines of sight have farther to travel. The lines of sight that have farther to travel are diverging from the station point and will be closer together at the picture plane than the lines of sight to closer objects of the same size. The sides of the street, the telephone wires, and the sidewalks all seem to be converging to a single point where they would vanish. The parallel lines appear to meet at this vanishing point which is an infinite distance from the observer. The three methods of drawing perspective are dependent upon the position of the object with respect to the picture plane.

In *parallel or one-point perspective* the object is placed so that two of its axes are parallel to the picture plane. The other axis, therefore, is perpendicular to the plane of projection and is a horizontal line. All horizontal lines that lie parallel to the receding axis will appear to vanish at the same point. The image of this point will appear at the intersection between a line of sight from the station point parallel to the receding axis and the picture plane. In the plan view the intersection is clearly seen because the picture plane is shown as an edge. In the pictorial view, the vanishing point will lie at the same elevation as the station point that is indicated by the horizon line. Any point of the object can be considered to lie along a theoretical line parallel to the receding axis. In the plan view, it is possible to see where the theoretical line pierces the picture plane. In the pictorial view, the piercing point is at the same elevation at every point on the object through which the theoretical line passes. From the piercing point to the vanishing point is the perspective of the theoretical line. Any point along the line may be located by lines of sight from the station point to the specific point on the object in the plan view. The piercing points of these lines of sight through the picture plane are then projected to the perspective of the theoretical line. Surfaces that lie parallel to the picture plane will project in true shape or configuration but will be smaller or larger than true size depending upon their position relative to the picture plane. Therefore, objects that have circular and curved surfaces are frequently positioned so that these surfaces are parallel to the plane of projection.

In *angular or two-point perspective* the object is positioned so that only one of its axes is parallel to the picture plane. The other two axes are horizontal lines which are inclined to the plane of projection. All lines parallel to the axis that recedes to the right will vanish or converge at the same point. Likewise, the lines parallel to the axis that recedes to the left will vanish at the same point. The location of the two vanishing points lie in the picture plane along the lines of sight through the station point parallel to the two receding axes. In the pictorial view the vanishing points lie on the horizon because they are horizontal lines. The procedure for locating any point on the object is the same as it is for one-point perspective. A point on the object can be considered to lie along a theoretical line parallel to one of the axes. The perspective of the theoretical line is drawn and the point sighted from the station point.

Oblique or three-point perspective is a projection of an object that is positioned so that all three axes are inclined at the plane of projection. Since the three axes are inclined to the picture plane, there are three vanishing points. In one-point and two-point perspective the receding axes were horizontal lines and the vanishing traces were therefore called the horizon line. The horizon line was at the elevation of the eye or station point. If a line from the station point is drawn perpendicular to the picture plane, the point that is located is the centre of vision. In one-point perspective, the centre of vision and the vanishing point coincide. In three-point perspective the centre of vision is located and the vanishing traces are drawn through it parallel to each of the three axes. The location of the vanishing points of the traces is found by the same procedure we used to find the other vanishing points. Lines of sight are drawn from the station point parallel to the three receding axes.

We have described only the basic theory of three-point perspective. The remainder of the drawing procedure is more cumbersome and probably accounts for the fact that three-point perspective has had very limited practical application.

Presentation Drawings

Before working drawings can be started it is generally necessary to prepare a presentation drawing of the tentative structure. This is done for several reasons. First, it combines the efforts of preliminary planning into a tangible proposal for a client's approval, making the presentation an actual "selling" instrument. Secondly, it offers a means for careful study of the structure’s appearance, by all concerned, upon which improvements or changes for final development can be based.

The presentation is the designer’s graphic concept of a building in its natural setting, made to represent the structure honestly, realistically, artistically, and in a manner easily understood by the average person. A great deal of unnecessary technical information is avoided to make the general concept more pronounced. Illustrated (rendered) perspective or elevation views showing the realism of light and shade, landscaping, and textures, are usually the most effective elements of successful presentation drawings. However, considerable latitude in the selection of views is possible, depending upon the nature of the proposal and the time allowed for its completion. Student projects usually include a perspective, a floor plan, several elevations, and a plot plan. The duplication of similar information on the various selected views should be avoided.

Many presentations consist of a perspective only. In fact, an architectural office will often give presentation work of expensive buildings to professional delineators, specialists in this type of work, for elaborate perspective renderings--frequently in colour. Many of such presentations have sufficient artistic merit to be used for promotional work, in brochures, and even in national publications.

If time is limited, effective presentations can be made with only a floor plan and a rendered elevation. Others may include a transverse section view or an interior perspective, if such features seem worthy of special consideration. Often residential presentations include a plot plan to show the proposed orientation of the home and grounds. In other situations a well executed freehand sketch may be adequate in showing client sufficient information about a structure. We see, then, that on a presentation drawing, the designer can give her or his creative abilities free rein in depicting the most interesting qualities of a building**.**

Successful presentations are done in almost all of the different art media; the most frequently used are: pencil, pen and ink, coloured pencil, water colour, tempera, pastel, and charcoal pencil. CAD models are immensely powerful, but often lack the warm feel of a hand-rendered presentation. Usually the mastery of one medium or another is the deciding factor in making the choice. After experimentation the designer will find that each medium has advantages as well as limitations. Pencil and pen and ink, for example, capable of executing sharp, fine lines can be used to reveal small details and various textures. But they are time-consuming when covering large areas. The pencil is comparatively easy to control, yet it should be selected as the medium for rather small drawings, as should pen and ink. The combining of pencil or ink linework with transparent watercolour wash for large areas overcomes this limitation and is often an intelligent choice of media for many architectural subjects. The beginning students would be wise in developing their rendering abilities in pencil work first, before attempting other media (Muller, 1976).

Overhead and Handout Files

Aesthetic Problems: Principles of Design

Principles of Design

- Appropriate Form
- Simplicity
- Function
- Representation
- Meaning
- Economy

Problems of Form and Composition

- Balance
- Contiguity
- Continuity or Flow
- Contrast or Dissonance
- Ecology
- Emphasis or Dominance
- Harmony
- Integration & Unity
- Material
- Motion and Transition
- Proportion
- Relevance
- Rhythm and Repetition
- Variety or Diversity

Elements of Visual Form

- Point
- Line
- Direction
- Position
- Scale
- Color
- Value
- Shape (Form)
- Texture

Metric Elements

- Point
- Line
- Plane
- Plate (Disc)

Stereometric Elements

- Prism & Antiprism
- Cylinder & Rod
- Cone
- Sphere
- Pyramid & Dipyramid
- Dome
- Cube & Polyhedra

Points, Lines, and Planes

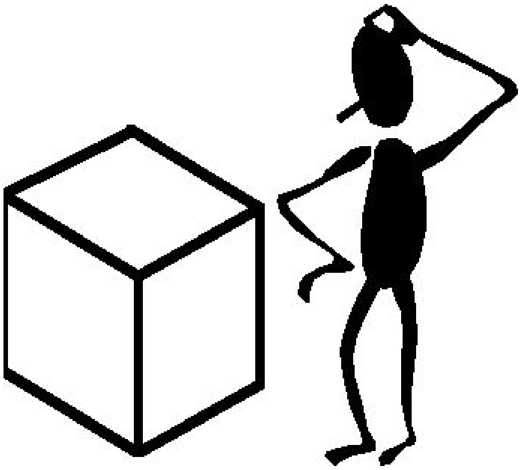
We *represent* objects with combinations of lines on paper, but we only *represent* the edges and the intersections of surfaces.

Lines are made of points. Geometric planes of all shapes are made of lines. 3D objects are made of combinations of planes. Some objects are made of planes with surfaces. Other objects consist of planes without surfaces. Plane surfaces of objects can be regular (flat table top), curved (drinking cup) or warped (Pringles potato chip) and are combined to form an object's shape and size. The edges of all these surfaces consist of intersecting lines. We represent the edges and intersections of surfaces as lines on our drawing paper.

1. Look at the solid block.
2. Picture the solid block in your mind.
3. Now picture an empty box in your mind.
4. How can we represent this box on paper?
5. Draw (Sketch) the box so that it looks 3D!
6. Now try to draw the solid block.

*** Remember, draw the edges as lines.**

*** Visualization is very important!**



Introductory statement:
Humans (and most animals) are accustomed to seeing things in three dimensions.

Design Drawing:
Pictorials

Rationale:
There are times when the client, fabricator, or builder is required to interpret a complicated object. The designer has the responsibility to provide drawings that easily convey 3-dimensional information. These types of drawing are pictorial drawings. Frequently pictorial drawings or 3D projections are used to supplement multiview drawings. The 2D views of objects in multiview projection must be integrated by the reader to mentally form the object. Multiview drawings have the disadvantage of being somewhat abstract. Pictorials have an advantage in general communication because they look like a picture.

Applications:
1. Detail drawings
2. Assembly drawings
3. Architectural plans
4. Illustrations in catalogs and handbooks
5. Schematic layouts
6. Presentation drawings

Prerequisite fundamentals:
Sketching

Terminology:
1. Axonometric
2. Oblique
3. Perspective

Symbology:

Convention:
The convention is dependent on the style of pictorial.

Introductory statement:
Parallel projections, including oblique and axonometric drawings, are simple, effective ways to communicate technical information. Multiview drawings are ineffective in transmitting information related to objects as they appear as a whole.

Design Drawing:

Oblique Projection and Drawing

Rationale:
Oblique projections are often used to supplement multiviews. They provide information on relationships of parts, or on objects as a whole. They are relatively easy to draw and they can be dimensionally correct.
Oblique projections are used extensively for objects that have curved and irregular surfaces which lie in parallel planes.

Applications:
1. Assembly drawings
2. Architectural (interior, exterior) drawings

Prerequisite fundamentals:
Projection, Point transfer

Theory/Explanation:
Oblique projection is a form of orthographic projection in which the lines of sight are oblique to the plane of projection.

Techniques:
1. Cabinet- 50% along receding axis
2. Cavalier- Full size along receding axis
3. General- 75% along receding axis

Convention:
1. Hidden lines are often eliminated.
2. Front, Right, Top orientation is most common.

Introductory statement:
Architects, designers, and engineers must often draw on methods of 3-dimensional representation to clarify complicated design ideas.

Design Drawing:
Axonometric Projection and Drawing

Rationale:
One group of 3D representational styles is called axonometric. Axonometric projections can be isometric, dimetric, or trimetric. Axonometric drawings are very useful for showing relationships of parts to each other. Axonometrics provide a good single picture of objects as they exist as a whole. Axonometrics are dimensionally correct.

Applications:
1. Assembly drawings
2. Architectural drawings (interior, exterior)

Theory/Explanation:
Axonometric projection is a form of orthographic projection in that it is based on projectors that are parallel with each other and perpendicular to the plane of projection. The object is projected onto a plane that is oblique to the three normal planes of projection.

Prerequisite fundamentals:
Projection, point transfer

Techniques:
1. Isometric- three equal angles between axonometric axes
2. Dimetric- two equal angles between axonometric axes
3. Trimetric- angles between axonometric axes are different
4. Plan dimetric- extension of plan view to 3D

Convention:
1. Hidden lines are often eliminated.
2. Illustration is often used to enhance the representations.

Introductory statement:
Designers often rely on very accurate and realistic 3-dimensional representations of objects for presentation and interpretation purposes.

Design Drawings:
Perspective Projection and Drawing

Rationale:
Perspective projections are the most realistic-looking of all the pictorial projections. They are preferred for the purposes of presentation.

Applications:
1. Presentation drawings
2. Design
3. Assembly drawings

Prerequisite fundamentals:
Projection, point transfer

Theory/Explanation:
In perspective, all lines of sight converge from one point. The observer is located at this finite position called the station point. Usually the picture plane is located between the station point and the object.

Techniques:
1. one-point (exterior, interior)
2. two-point (exterior, interior)
3. three-point
4. office method layout of perspective projection

Convention:
Illustration is often used to enhance perspective drawings.

Introductory statement:
In engineering and design, a system of projection that eliminates the inherent size deviations of perspective must frequently be used.

Design Drawing:

Multiview Projection and Drawing

Rationale:
Technical information related to the shape of simple parts can often be conveyed by the spoken or written word. However, the addition of details to an object increases complexity, and precise methods must be used for adequate description. The production of objects, whether architectural or mechanical, requires an accurate and complete graphic description of both shape and size. Although photographs and pictorials help to describe objects as whole entities, they do not represent exact shapes and sizes. Multiview projection is the most frequently used system in graphic representation and analysis. It is a system by which an object may be described completely through the use of two or more projections. Each projection is a two-dimensional "view" of the object. A systematic arrangement of the views assures completeness in presentation and ease in reading.

Applications:
1. Communication of graphic information in the from of:
2. Detail drawings
3. Assembly drawings
4. Working drawings
5. Architectural (interior, exterior, construction) plans

Prerequisite fundamentals:
Sketching, visualization skills, instrumental/CAD drawing skills

Explanation/Theory:
Multiview projection is the projection of an object onto a plane by means of projectors which are parallel to one another and perpendicular to that plane. The true shape of a surface of an object is shown in a view only when the plane of projection is parallel to that surface. Viewing distance can be at infinity. The three planes of projection on which six principal views can be projected are: frontal, profile, and horizontal. Any given view will represent two of three (height, width, depth) dimensions.

Symbology:
1. Lines are used to represent objects. Lines represent intersections of surfaces, the edge of planes, and limiting elements of curved surfaces. Frequently, a line represents more than one thing at a time.
2. Object (visible, continuous) lines
3. Hidden lines
4. Center lines

Technique:

1. Glass box visualization
2. Projectors and miter lines
3. Point transfer

Convention:

1. Placement of views is critical. Indeed, it is standardized.
2. Principal view choice (object orientation) is critical. Most descriptive view, or the view that defines the object's characteristic shape, is placed in front position. Often, the natural position of usage is given precedence. The number and selection of views is governed by the shape or complexity of the object. A view should not be drawn unless it clarifies description.
3. One view is often used to describe thin objects.
4. Two principal views are often used to describe cylindrical and conical objects.
5. At least two (three are common) complete principal views must be used to describe complex objects.
6. Front, top, and right side views are the most common principal views used for representation.
7. Half and partial views are often used to simplify representation of simple and symmetrical objects.
8. Sectional views, to reveal interior details, are often used to supplement principal views.
9. Auxiliary views, to show true shape of inclined and oblique surfaces, are often used to supplement principal views.
10. Hidden lines are used to represent "hidden" surfaces.
11. Object lines supercede hidden lines.
12. The most complex objects can be adequately described with no more than four, or possibly five well-chosen views.
13. The spacing between views should be equal. Spacing between views and borders should be symmetrical.
14. Views should be centered within drawing area.

Supplementary information:

Multiview is often called orthographic and orthogonal projection. It is a form of parallel projection.

Practice:

*It is common practice to:

1. layout front view and project adjacent views.
2. use mathematical centering techniques.

Introductory statement:
We are challenged to represent any object in space- their intersecting surfaces- with any number and combinations of lines.

Design Drawing
Points, Lines and Planes in Multiview

Rationale:
Surfaces of 3D objects are bound by lines comprised of points. These surfaces, whether plane (normal, inclined, oblique), curved or warped intersect to define and form object shape and size. We represent these intersections as lines on our paper space. Pictorials represent objects as we see them but do not accurately describe the shapes of the objects. Multiview drawing accurately describes the shapes and sizes of an object and we must analyze the various aspects of the object to accurately represent it. Such an analysis requires a knowledge of lines and planes and their patterns of space occupancy.

Applications:
All sketching and design and engineering drawing.

Technique:
1. We visualize and project what we see onto a 2D plane (paper space).
2. In pictorials, we draw what we see from one position or view.
3. In multiview, we draw what we see from three different positions or views (frontal, profile, horizontal).
4. All points are projected and represented in all views
5. All external lines of an object must be visible, regardless of the object's orientation in space.
6. When planes intersect in one view, that intersection is represented in adjacent views as lines.
7. Curved planes that intersect other planes create lines.
8. Curved planes that fall tangent to other planes do not create lines of intersection.
9. Lines that lie parallel to planes of projection are true length lines.

Introductory statement:

By means of a limited number of carefully selected views, the external features of the most complicated designs can thus be fully described.

Design Drawing:

Sectional Views

Rationale:

We are frequently confronted with the necessity of clearly explaining complicated interior shapes and contours of objects. Through the use of sectional techniques, we can often clarify internal shapes and construction details.

Applications:

1. Detail drawings
2. Assembly drawings
3. Architectural plans

Prerequisite fundamentals:

Multiview projection, pictorial projection, detail drawing, assembly drawing

Terminology:

1. Full section
2. Half section
3. Broken-out
4. Revolved
5. Removed
6. Offset
7. Aligned

Symbology:

1. Conventional breaks
2. Section lining
3. Cutting plane

Technique:

1. Use 45 degree section lines for multiview.
2. Use 60 degree section lines for isometric (opposing for half sects).
3. Use 22.5 degree and 67.5 degree section lines for oblique.

Convention:

1. Sectional views are used to supplement principal views.
2. Full sectional views often replace principal views.
3. The cutting plane line in a full section is often omitted.
4. The general section lining symbol is representative of all materials.
5. Full sections are seldom utilized for pictorial drawings (half and broken-out are most common
6. Ribs, webs, fasteners, etc. are not sectioned.
7. Conventional breaks are recommended to shorten elongated objects.

Introductory statement:
All shape description requisites can be satisfied by utilizing four, possibly five, different types of planes of projection.

Design Drawing:
Primary Auxiliary views

Rationale: In order to show the "true surface" projection of a plane surface that is not parallel to the regular planes of projection, it is necessary to assume a line of sight perpendicular to that plane surface. When projected, the resulting view is an auxiliary view.

Applications:
1. True shape, true size of surfaces.
2. True shape of curvilinear figures, or dihedral angles.
3. Reverse construction.
4. True length of lines.
5. Pictorials

Prerequisite fundamentals: Multiview projection, Point transfer, Edge projection of a plane, Plotted curves.

Technique: • Label Points— Use color lines— Visualize
1. Folding line method.
2. Reference plane method.
   a) Coinciding with front surface.
   b) Cutting through an object.
   c) Coinciding with back surface.
   d) Cutting through any intermediate points.

Convention:
1. Hidden lines are utilized only if they clarify shape.
2. Partial views are often utilized.
   a) Break lines
   b) Extension/projection lines
   c) Center lines
3. Half views of symmetrical objects
4. Auxiliary sections
5. Dimension surfaces, contours, and angles in the view where they appear as true shape, true size.

Supplementary information: Classification of primary auxiliary views
1. Depth auxiliary
2. Width auxiliary
3. Height auxiliary

Introductory statement:
A plane (flat) surface is seen in its true shape only when it lies parallel to the plane of projection.

Design Drawing:
Secondary Auxiliary views

Rationale:
There are times when it may be necessary to show the true shape projection of a plane surface that does not appear as an edge in any of the principal views. Hence, a secondary auxiliary view must be projected.

Applications:
1. True shape, true size of oblique surfaces.
2. True shape of curvilinear figures.
3. Reverse construction.

Prerequisite fundamentals:
Multiview projection, Primary auxiliary projection, Point transfer, Edge projection of a plane, Point projection of a line, Plotted curves, Dihedral angle projection, Reverse construction.

Technique:
1. Folding line method
2. Reference plane method
   a) Edge projection of the oblique plane
   b) Secondary auxiliary plane projected perpendicular to primary auxiliary plane

Convention:
1. Hidden lines are utilized only if they clarify shape.
2. Partial views are often utilized.
   a) Extension/projection lines
   b) Center lines
3. Dimension surfaces, contours, and angles in the view where they appear as true shape, true size.

Supplementary information:
A primary auxiliary is always projected from a principal view and a secondary auxiliary is always projected from a primary auxiliary.

Practice:
1. Think and visualize
2. Label points
3. Project with colored pencils
4. Double-check

Introductory statement:
The nature of technology and industry challenges us to completely describe an object with techniques that exploit shape and size description along with specification details.

Design Drawing:
Detail Drawings

Rationale:
Provisions must be made for the complete communication of technical information as it relates to the construction of individual parts. It is only through the planning, drafting, and utilization of detail drawings that this information can be transferred accurately. Detailing is the single most important part of industrial drafting.

Applications:
1. Industrial use
2. Person to person communication
3. Industry to industry communication
4. Necessary for any non-standard part that is destined for a production environment

Prerequisite fundamentals:
Multiview projection (principal view, auxiliary view, sectional view), Dimensioning, Awareness of technical standards, Notation of specifications and calculated data

Technique:
1. Procedural approaches are recommended:
2. Determine the most descriptive orientation for the component surfaces.
3. Select views for accurate shape description.
4. Layout all necessary views before adding any dimensions or notes.
5. Analyze the actual shape of component and its characteristic views for size description..
6. Mentally divide the component into its geometric shapes.
7. Place size dimensions on each form.
8. Carefully select location centers and surfaces.
9. Place location dimensions.
10. Add overall dimensions.
11. Add descriptive notes.
12. Analyze part, and complete description with notation of specifications.
    a) Type of material
    b) Treatments
    c) Finish
    d) General tolerances
    e) Number Required
    f) General notes

13. Complete descriptive title block.
    - a) Sheet number
    - b) Scale
    - c) Date
    - d) Part name
    - e) Drafter's name
14. Meticulously review with checklist.

Convention:

1. Detail drawings exploit multiview drawing techniques.
2. Standard detail drawings include:
    - a) Graphic shape description
    - b) Size description (Figured dimensions)
    - c) Specifications
    - d) Additional information
3. Checklists are utilized as a precaution.

Typical checklist:

1. **Shape**- Is the item described accurately? Were effective views projected? Were partial views used where possible?
2. **Size**- Is the part completely and accurately dimensioned?
3. Will it be necessary for fabricators to calculate dims? Is there repetition? Are dims ambiguous? Legible? Are there omissions or Errors?
4. **Tolerances and Fits**- Are they suitable for proper functioning of the part? Are they realistic? Can they be more liberal?
5. **Clearances**- Is there freedom of movement for moving parts?
6. **Standard parts**- Were standard parts used where possible?
7. **Material**- Has proper material been specified? Heat treatment? Finishes? Are finish marks properly notated?
8. **Notes**- Are notes clear and legible?

Supplementary information:

Detail drawings can be, and often are, utilized as working drawings.

Practice:

1. Think!
2. Adhere to standards and conventions.
3. Critically examine drawings.

Introductory statement:
Mass production and construction techniques demand that large quantities of individual components be manufactured to a required dimensional accuracy for interchangeability and/or assembly.

Design Drawing
Dimensioning

Rationale:
A systematic system of dimensioning is critical to supply accurate, adequate, and concise information. Completeness is a virtue in supplying detailed information related to size and location. Any object can be mentally broken down into geometric components. Objects can be thought to consist of a combination of spheres, cylinders, prisms, cones, pyramids, or segments of these geometric forms.

Applications:
1. Detail drawings
2. Working drawings
3. Architectural plans

Prerequisite fundamentals:
Multiview projection, pictorial projection

Symbology:
1. Dimension lines
2. Extension lines

Technique:
Analyze object through geometrical breakdown
2. Place feature/form dimensions (size)
3. Place location/position dimensions (location)
4. Place overall dimensions
5. Check

Convention:
Clarity is valued!
1. Geometric features of an object must be represented in size and location to one another.
2. The use of either SI or decimal dimensions are accepted in mechanical drafting.

The following are considered to be critical general principles for dimensioning:
1. Place dimensions where you would expect to find them.
2. Dimensions are shown in the view that most clearly represents the form of the feature.

3. Dimension, extension, and leader lines should not cross each other unless necessary. Dimension lines should not be broken except for the insertion of a dimension.
4. Sufficient dimensions should be shown to clearly define size, shape and position of each feature.
5. A feature should not be located by more than one dimension. Superfluous dimensions should not be expressed.
6. Unless clarity is improved, dimensions should be placed outside the representation of the part
7. Dimensions should be placed between the views unless clarity is improved by doing otherwise.
8. Each dimension should be expressed clearly so that it can be interpreted in only one way.
9. Center lines, object lines, or extension lines should not be used as dimension lines.
10. Dimensioning to hidden lines should be avoided.
11. Overall (H,W,D) should be expressed.
12. Standard spacing should be used for all dimensioning.

Supplementary information:

1. Dimensions can be placed with a unidirectional or aligned approach. Unidirectional is most common.
2. Mechanical styles and architectural styles of dimensioning differ.

Introductory statement:
A set of working drawings is valuable only when the drafter has effectively represented the location of constituent parts as they appear in the completed product.

Design Drawing:
Assembly Drawings

Rationale: Following the detailing of individual parts, it is imperative that the relationship of the parts to one another be illustrated. As detail drawings provide information on individual parts, assembly drawings provide information on the product as a unit.

Applications:
1. All production industries.
2. Service industries.
3. Patent applications
4. Communication of specific information regarding design, assembly, operation, function, and/or installation.
5. Checking

Prerequisite fundamentals:
Multiview drawing, oblique drawing, axonometric drawing, perspective drawing, exploded part techniques, pictorial dimensioning, pictorial sectioning, part labeling

Technique:

Convention:
1. The convention is dependent on the type of assembly drawing.
2. Few, if any hidden lines are drawn.
3. Sections are utilized to show the position of standard parts, or minor details in assembly. The standard parts themselves are not sectioned.
4. It is common, but not standard to use pictorial assembly representations.
5. Exploded techniques are exploited.
6. Constituent parts are always labeled and/or identified by name.
7. Dimensions are very seldom included.
8. One product per sheet
9. Illustration techniques are common.

Supplementary information:
1. Outline assembly drawings (one, two, or three views) are utilized, but often are lacking in presentation clarity. Overall dims are usually notated on these types of drawings. Few, if any hidden lines are drawn.

2. Explicit information is often needed to show the function of a single or special part. In the case, an operation assembly may have to be generated to supplement the main assembly drawing.
3. Diagram assembly drawings are used to show the location and form (shape) of parts in assembly. Usually a one-view drawing.
4. Design assemblies are similar to outline assemblies, but design information is provided for major parts.
5. Subassembly drawings are used to show the assembly of small parts of large or complex products.
6. Installation assembly drawings provide enough information for the complete assembly, installation, and operation of product. Information provided may include dimensions and instructions for assembly. Installation assemblies often consist of a pictorial drawing of the product and an exploded assembly.
7. A working assembly drawing includes all the information needed to fabricate an object (detail assembly).

Practice:
1. Determine the use of the drawing.
2. Analyze object.
3. Decide on most effective representational style.

Introductory statement:
With respect to drawings that are destined for a production environment, all relevant information must be provided to insure the accurate fabrication of the object described.

Design Drawing:
Working Drawings

Rationale:
In order to facilitate the manufacturing process, working drawings must be generated. Working drawings are the specifications for the manufacture of a design. Indeed, working drawings pave the road from idea to product.

Applications:
Construction and Production Industries
1. production of single parts
2. assembly of constituent parts into a comprehensive object
3. used as one of the final steps in the design process

Prerequisite fundamentals:
Multiview projection, Detail drawing, assembly drawing, oblique drawing, axonometric drawing, perspective drawing

Technique:

Convention:
1. Working drawings must follow the format and/or practices of the shop or industry in which they are produced (i.e. usually ANSI, but may be DOD, NASA, U.S. Steel, Stelco, IBM, etc.).
2. Number of details per sheet
    a) small structures or few parts- 1 sheet
    b) large or complex mechanisms- several sheets
3. Standard parts are not drawn. They are, however, included in the parts list or bill of material.
4. Accurate communication between industries is imperative. General conventions must be adhered to.
    a) Proper line technique
    b) Dimensions and notes must be accurate and easy to read
    c) Terms and abbreviations must be standard.
    d) Completed drawings must be reviewed (checking-checklist).
1. For objects that consist of more than one part, the following should be included:
    a) Details of non-standard parts
        i. Graphic shape description (multiviews)
        ii. Size description (Figured dimensions)

        iii. General notes (Finish, Material specs, Type of material, Number required,
        iv. General tolerances)
        v. Descriptive title (name of part, scale, name of draftsperson)
    b) Assembly of parts into unit
        vi. Description of parts in relation to one another
        vii. Shows parts in their functional position
        viii. Designates parts by number
        ix. Used for checking purposes
    c) Parts list
        x. Item number
        xi. Part name
        xii. Quantity
        xiii. Material
- List parts in order of importance with larger parts first

Supplementary information:
Working drawings can be:
1. a detail drawing, or
2. a working drawing assembly.

A set of working drawings will include detail drawings of the individual parts and assembly drawings of the assembled unit.

Practice:
1. Concentrate on:
2. Choice of views
3. Dimensions
4. Standard parts
5. Notes
6. Clearances

Introductory statement:
Interchangeable manufacturing, by means of which parts can be made in widely separated localities and then be brought together for assembly, where the parts will all fit together properly, is an essential element of mass production. Without interchangeable manufacturing, modern industry could not exist, and without effective size control by the engineer, interchangeable manufacturing could not be achieved...

Design Drawing:
Production Dimensioning (Tolerances and fits)

Rationale:
The critical nature of production dimensioning is such that the proper functioning and mating of parts or surfaces and the cost of producing and assembling of parts are dependent upon it. Dimensions are used primarily on detail drawings for the guidance of the fabricators who are responsible for the manufacture of the component parts of various mechanisms or products. However, in production, exact sizes are not needed, only varying degrees of accuracy according to functional requirements. It is impossible to make anything to exact size. So what is needed is a means of specifying dimensions with respect to the required degrees of accuracy. Production dimensioning facilitates:

1. interchangeable manufacturing.
2. competitive and economic fabrication.
    a) varying degrees of accuracy
    b) controls form, orientation, and location.

Applications:

1. Production environments.

Prerequisite fundamentals:
Detail drawing, conventional dimensioning

Terminology:

2. Allowance-
3. Basic size-
4. Maximum dimension-
5. Minimum dimension-
6. Fit-
7. Limits-
8. Mean size-
9. Nominal size-
10. Tolerance/Tolerance Band-
11. Tolerance Grade-
12. Tolerance-
    a. Bilateral tolerance-

   b. Unilateral tolerance-

13. Maximum material condition (MMC)-
14. Least material condition (LMC)-

Technique:

1. Limit dimensions
2. Plus and minus dimensions
3. General note
4. Preferred fits

Convention:

1. Chain dimensions are avoided (tolerance accumulation).
2. Drawings are checked to make sure that parts will assemble and function under all dimensional conditions that are within limits.
3. Tolerances or limits should have an equal number of digits following the decimal point.
4. Unilateral tolerances are usually given for holes and shafts (direction of variation must be specified).
5. Bilateral tolerances are usually given with locational dimensions, or dimensions that can vary in either direction.
6. Bilateral tolerances are usually equal.
7. Conventional tolerancing is used for size description, GDT is used for form description.

Supplementary information:

Practice:

Introductory statement:
Mating parts require machining accuracy because they are directly related to the operation and/or function of the engineered design. When two or more parts are mated to form an assembly, their dimensions and tolerances must fit together with predetermined limits.

Design Drawing:
Preferred or Engineered Limits and Fits

Rationale:
Fits between parts will dictate the proper assembly and performance of a product. The expression of these fits is dimensional, and involves the adoption of engineered limits for these parts. Thus, the limits and fits of parts are expressions of manufacturing tolerance. The use of preferred fits has been a basis for improvements in the efficiency of engineering and design, manufacture, quality assurance, and use and maintenance of the product.

Applications:
1) Production drafting.
2) Shafts & holes
3) Keys and keyways

Prerequisite fundamentals:
Detail drawing, assembly drawing

Terminology:

1. Limits of size- pertain to the maximum and minimum sizes that are permitted for a particular part.
2. Fit- relationship between assembled parts. The range of tightness or looseness that may result from the application of a specific combination of allowances and tolerances in mating parts.
3. Clearance- a positive value found by the mathematical difference between the sizes of a hole and shaft.
4. Interference- a negative value found by the mathematical difference between the sizes of a hole and shaft.
5. Basic hole (hole-basis) system-
6. Basic shaft (shaft-basis) system-

Symbology:
RC1-RC9, LC, LT, LN, FN1-FN5

Technique:
1. Determine type of engineered fit.
2. Determine basic size (hole-basis or shaft-basis).
3. Reference ANSI table for limits.
4. Dimension

Convention:
1. Basic hole system is common.
2. Limit dimensioning is common.
3. Preferred/engineered sizes, allowances, and tolerances are recommended for fits between cylindrical components.
4. Metric fits are based on the same principle, but ISO R286 standards are utilized.
5. In practice, it is advisable to adhere to the preferred limits and fits of the standard.
6. The design determines the fit.

Supplementary information:

Fits are broken down into three major categories:
1. Clearance
2. Transition
3. interference. More specifically:

    a. Running and sliding fits (RC)- designed to provide similar running performance, with appropriate lubrication allowance, throughout the specified ranges of sizes.
    b. Locational fits (LC, LT, LN)- designed to determine the location of parts.
    c. Force fits (FN)- a special category of interference fit that is characterized by the maintaining of constant bore pressures through the entire range of sizes.

Introductory statement:
Sophisticated designs require a precise drawing language that can facilitate the interpretation of specifications. As world class manufacturing becomes the convention, the need for a symbolic communication system becomes an urgent necessity. Drawing specifications must assure that after production, the parts can be easily assembled and interchanged with similar parts made by the same production methods.

Design Drawing:

Geometric Dimensioning and Tolerancing (GDT)

Rationale:
The use of GDT can mean a clearer expression of the intent of the design. GDT can vastly improve communication in the cycle from design to manufacture. The amount of feature control afforded in GDT far exceeds that of conventional dimensioning. The additional control and the resulting improved communication allow companies that use GDT to be more competitive in the national and international markets. Basically, GDT facilitates precision by providing for:

1. The largest functional tolerance zone possible given two mating features,
2. Tolerancing techniques for form, orientation, profile, location, and runout.
3. An international system of precise interpretation of design requirements.

Applications:

1. Production environments.
2. Inspection of parts.

Prerequisite fundamentals:

1. Detail drawing
2. Dimensioning
3. Tolerancing

Terminology:

1. Geometric tolerance- maximum permissible variation in form, orientation, profile, location, or runout from that which is specified.
2. True-position dimension- theoretical exact location established by basic dimensions.
3. Datum- a point, plane, or surface from which dimensions are measured when specified. A datum has an exact form or fixed location for purposes of manufacture or measurement.
4. Datum feature- a feature of a part such as an edge, surface, or hole that forms the basis for a datum or is used to establish a datum.
5. Datum dimension- a dimension that establishes the true position of a datum or datum target.
6. Assumed datums-

7. Basic dimension- the theoretical exact size, profile, orientation, or location of a feature or datum target.
8. MMC-(M)
9. LMC-(L)
10. Virtual condition- overall envelope of perfect form.
11. RFS- (S) regardless of feature size.

Symbology:
1. Geometric control frames
2. Geometric characteristic symbols
3. Datum identifying symbols
4. Basic symbols

Technique:

Convention:
1. For sizes, conventional tolerancing methods are used.
2. The toleranced dimensions for the size of a feature control the form as well as the size.
3. Geometric tolerancing is used only when the shape can be critical to the function of the part or the interchangeability of parts (degree of precision for interrelated parts).
4. If any surface does not have a geometric tolerance specified, the form is allowed to vary within limits of size.
5. When datums are not specified, linear point-to-point dimensions are applied.
6. Shape description and the resultant geometric characteristics supplement all drawings.
7. Form tolerances that always require datums: parallelism, perpendicularity, angularity, and runout.
8. Form tolerances that never require datums: flatness, straightness, roundness, and cylindricity.

Supplementary information: Working Definitions

FORM TOLERANCES

1. Flatness- the condition of a surface having all elements in one plane.

2. Straightness- the condition where an element of a surface is a straight line.

3. Circularity (Roundness)- the condition of a surface of revolution such as a cylinder, cone, or sphere where all points of the surface intersected by any plane (1. perpendicular to a common axis of a cylinder or cone or 2. passing through a common center of a sphere) are equidistant from the axis.

4. Cylidricity- the condition of a surface of revolution in which all elements form a cylinder.

5. Profile of a surface or line- method used where a uniform amount of variation may be permitted along a line or surface. The line or surface may consist of straight lines or curved lines, the latter being either arcs or irregular curves.

6. Parallelism- the condition of a surface, axis or line that is equidistant at all points from a datum plane or axis.

7. Perpendicularity (squareness)- the condition of a surface, axis, or line that is at right angles to a datum, plane, or axis.

8. Angularity- the condition of a surface or line that is at the specified angle (other than 90) from a datum plane or axis.

RUNOUT TOLERANCES

1. Runout- the condition of perfect form and axial alignment of two or more surfaces of revolution such as cylinders, cones, or contours and may include plane surfaces perpendicular to and generated about a common axis. In essence, runout establishes composite form control of concentricity, perpendicularity, roundness, straightness, flatness, angularity, and parallelism for a part having a common axis.

2. Circular runout- the maximum permissible surface variation at any fixed point during one complete rotation of the part about the datum axis.

3. Total runout- the maximum permissible surface variation at all surface elements during one complete rotation of the part about the datum axis.

LOCATION TOLERANCES

1. Concentricity- the condition of surfaces of revolution such as cylinders, cones, or spheres, wherein they have a common axis.

2. Symmetry- a condition wherein a part or a feature has the same contour and size on opposite sides of a central plane, or a condition in which a feature is symmetrically disposed about the central plane of a datum or feature.

3. Positional tolerance- a term used to describe the perfect or exact location of a point, line, or plane of a feature in relationship with a datum or other feature.

Introductory statement:
Along with being common household items, threaded fasteners are vital to the purposes of industrial design. The automobile industry alone uses over 40 billion threaded fasteners annually. More than 250,000 nuts, bolts, and other fasteners in more than 2000 different sizes were required to hold together the first stage only of the Saturn 5 rocket.

Design Drawing:
Threads

Rationale:
Fundamental to engineering design is the use of threaded fasteners. Drawings must clearly communicate the type of threaded fastener that the designer has specified. In addition, unique features of many threaded fasteners must be detailed.

Applications:
1. Assembly drawings
2. Customized threaded fasteners

Prerequisite fundamentals:
Multiview drawing, "S" breaks, Isometric drawing, Exploded techniques, Knowledge of thread terminology and symbology

Technique:
1. Detailed representation (close approximation of appearance)
2. Schematic representation
3. Simplified representation
    a) External threads (in elevation)
    b) Type of screw, form, size?
    c) Major Diameter?
    d) Minor diameter (Major dia -2x thread depth)?
    e) Length?
    f) Details for head (angle, diameter)?
    g) Internal threads (in elevation)
    h) Tap drill size?
    i) Major dia of thread?
    j) Tap drill depth= 3 pitches beyond tap bottom
    k) Tap depth= 2 pitches longer than fastener (material specific)
    l) external (plan view)
    m) Details for head (angle, diameter)?
    n) Clearance hole in other member= .03 + major diameter
    o) Countersink
    p) ***Thread designation***

4. Fastener heads, nuts

Convention:

1. Schematic or simplified symbols are used to represent threads under 1 in. in diameter.
2. Symbols (schematic & simplified) are the same for all forms of threads
3. Simplified symbol is most common
4. Simplified is not used where it may be confused with other drawing detail
5. Detailed representation is rarely used.
6. Threaded shafts are often shortened and conventional "S" breaks or phantom lines are drawn.
7. Sectional views are often applied to reveal threaded fasteners (fasteners are not sectioned)
8. Thread notes are used to specify exact type of fastener and fit.
9. Generous tap drill depths should be provided.
10. Physical sizes of threads should be drawn accurately.

Supplementary information:

Threads are utilized to:

1. hold parts together
2. adjust parts with reference to each other
3. transmit power or motion.

Common types of thread series are:

1. coarse
2. fine
3. extra fine.

Common thread systems or forms are:

1. Unified (U.S. standard)
2. American National
3. British standard Whitworth
4. Sharp V (Sellers)
5. Metric
6. Square
7. Acme.

Common types of metal fasteners: machine screws, cap screws, setscrews, bolts, studs, carriage bolts...

1. Thread classes- fit based on tolerances and allowances
2. Thread nomenclature:
3. Thread designation:

Practice:

1. Fastener templates
2. Thread specification charts

Introductory statement:
Often, it is desirable to fasten parts together permanently, in which case, mechanical fasteners will not do.

Design Drawing:

Welding Representation

Rationale:
Since welding is used so extensively, it is essential to have an accurate method of showing on working drawings the exact types, sizes, and locations of welds desired by the designer.

Applications:
Working drawings

Prerequisite fundamentals:
Detail drawing, Assembly drawing

Terminology:

- Types of welded joints
  - Butt-
  - Corner-
  - Tee-
  - Lap-
  - Edge-
- Types of welds
  - Gas-
  - Arc-
  - Resistance-

Symbology:
Basic welding symbol
Additional symbols

Technique:
** The arrow points to the joint where the weld is to be made, attached to the reference line or shank is the desired weld symbol.

Convention:
1. The welds themselves are not drawn, but are clearly and completely indicated by the welding symbols.
2. The joints are shown as they would appear before welding.
3. Dimensions are given of the individual pieces.
4. Each component piece is identified by encircled numbers and by specifications in the parts list.
5. Symbols are drawn mechanically or with templates.

Supplementary information:
A welding drawing is an assembly drawing in the sense that it provides information on a number of pieces fastened together as a unit.

S. Petrina. (2003). *Introductory design drawing for technology teachers*. Vancouver: Tech no-Printing Press.