# 3-D Modeling/GD&T – Cornerstones for Manufacturing Education

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## Abstract

Three-dimensional (3D) modeling allows graphics to be taught as the virtual manufacturing of a part. Modeling of parts begins with a primitive – raw material. The primitive is then modified using features such as slots, pockets, holes, etc. – manufacturing methods. By using 3D modeling, students can be taught about both engineering graphics and manufacturing simultaneously; and thus have a better understanding of how to design parts for manufacturability.

Geometric dimensioning and tolerancing (GD&T) encourages a dimensioning philosophy that defines a part based on how it functions in the final product. GD&T should be taught not merely as a set of symbols that are applied to a two-dimensional drawing, but rather as a functional requirement of the design, manufacture, and measurement of the part. While teaching GD&T the instructor should also incorporate fundamental concepts of metrology, which will provide students with a better understand of the "symbolic language" of GD&T and its affect on the manufacturing and inspection processes. GD&T and three-dimensional modeling both depend heavily on the use of datum planes and axes. By requiring students to be consistent in the application of datum planes/axes and location dimensions, the instructor emphasizes the importance of capturing design intent (manufacturing intent) in the model thus further enhancing the students understanding of the impact of design on manufacturing.

This paper discusses the importance of three dimensional-modeling and geometric dimensioning as they relate to manufacturing and outlines a two-semester course sequence for presenting this material in a Manufacturing Engineering Technology curriculum.

## A Need to Follow the Change in Communication Models

A survey by Clark and Scale of North Carolina State University[1] on current trends in technical graphics revealed that 54% of the respondents still teach manual drafting and that 92% of the respondents still teach two-dimensional (2D) CAD. The survey also revealed that only 54% of the respondents offered 3D constraint based modeling and that only 66% the respondents use some geometric dimensioning and tolerancing. It is not within the scope of this paper to address the pros and cons of continuing to teach manual drafting and 2D CAD. However, it seems clear that many programs have failed to keep up with the rapid technological changes in the technical graphics area and are not emphasizing the change in the way engineering communicates with manufacturing.

In the pre-computer era of serial design, 2D drawings were the primary means of communication between the engineering and manufacturing entities. As we moved from manual drafting to 2D CAD technology, the focus was primarily on automating and improving the productivity of the 2D drafting process.[2] However, the means of communicating between engineering and manufacturing remained the same. As the communication model between engineering and manufacturing began to move from a serial model to a concurrent model and as the cost of computer power dropped, three-dimensional (3D) modeling began to form its roots. Unlike its 2D counterpart, 3D models allowed the creation of a virtual part as opposed to a picture that merely defined the part. By having a virtual part, it was possible for engineering and manufacturing to work on the part concurrently. The time to market was reduced and the time gap between interdepartmental communications was shortened. The result was a much improved communications model. Today, working drawings are generated from the model only as needed, and often designs or products are produced without the generation of drawings at all.[2] It seems clear that the concurrent model has permanently replaced the serial model and thus the scope and content of technical graphics courses should follow. Just as the 3D model allows concurrent activities in the work place, it also provides an opportunity in the classroom to teach technical graphics, manufacturing, and metrology concurrently, allowing for a better understanding of design for manufacturability.

## The 3D Model – a Virtual Manufactured Part

The 3D Model is a virtual part. The mathematical model developed in constraint based 3D modeling systems allow the model to be manipulated for purposes of stress analysis, machining, rapid prototyping, and virtual assembly. It is acknowledged that many of the systems are somewhat proprietary in nature and that it is not the role of a university technical graphics course to teach proprietary software. However, it is clear that there are fundamental concepts shared by all leading solid modeling packages.[3] The emphasis in the technical graphics course should be on the fundamental concepts and not on the proprietary features of the software.

Most constraint based 3D modeling systems begin with a single primitive, such as a block, cylinder, sphere, or cone. The primitive is the equivalent to beginning the manufacturing process with a piece of raw material of similar shape. The primitive is then modified using features. These features often carry names that are derived from manufacturing terminology such as hole, slot, groove, boss, etc. While it is not feasible to teach in-depth manufacturing processes and technical graphics simultaneously, it is easy to provide a basic understanding of manufacturing by demonstrating the method in which the feature would be manufactured. The following example relates the creation of a slot in a block using EDS' Unigraphics software and an explanation of how the slot would be cut into the block during manufacturing. Similar examples can be developed with other features and other software packages.

- Given a block, the slot feature is selected. The user is given the choice of several different types of slots: rectangular, ball-end, U-slot, T-slot, and dovetail. By taking a short trip to the machine shop or by showing a video clip, the instructor can explain that a slot is created in a block by the use of a milling machine. The instructor can also obtain tooling for one or more of the different types of slots, so that the students can see the tooling first hand.

- Next, the user must select a planer placement face. The instructor explains to the student that the planer placement face is the face in which the bottom of the tool will make contact. By literally holding a block in one hand and a milling tool in the other hand, the student can see first hand the meaning of planer placement face and the relationship of the tool to the block in the manufacturing process.
- Unigraphics then requests that a horizontal reference be selected. The instructor explains that the horizontal reference is a line parallel to the direction of travel of the tool. Again a simple demonstration with a block and milling tool provides the student with both a clear understanding of "horizontal reference" and how the milling process will occur.
- The user is then requested to enter values for "width," "depth," and "length."
    - Width can be shown to be equal to the diameter of the cutting tool. Although this does not explain multiple passes on very wide slots, it does provide a clear understanding of a simple slot.
    - Depth can be shown by demonstration, using the block and milling tool, to be the amount of penetration from the planer placement face.
    - Unigraphics requires that the length of the slot be long enough to account for the diameter of the tool, which leaves a half-round on each end of the slot; the same as would occur if one were actually milling the slot on a milling machine. For example, if a 1" wide slot were being cut through a 2" block, the length of the slot would be equal to the size of the block plus the diameter of the cutter (2" + 1" = 3"). Demonstration of how this works in the manufacturing environment helps the student to understand both the manufacturing process and how to create the slot in the CAD system.
    - Lastly, the slot must be located with respect to the block. Again, with the block and tool, the instructor can demonstrate how the slot might be cut from an edge (line to line) or located off the center of the tool via a location dimensions.

A demonstration such as this helps the student in understanding both the terminology of the CAD system and the manufacturing process.

## Completing the Loop with Inspection Techniques

Geometric tolerancing encourages a dimensioning philosophy called "functional dimensioning." Functional dimensioning is a dimensioning philosophy that defines a part based on how it functions in the final product.[4] GD&T provides the designer a tool by which to communicate design intent to both the manufacturing and inspection entities. By specifying datums, form control, and positioning requirements, the designer stipulates precise manufacturing and inspection conditions. GD&T textbooks typically demonstrate the meaning of GD&T symbols by showing how one goes about measuring a part. Functional gaging is often the measurement technique that is utilized. The incorporation of the understanding of functional gaging and other metrology concepts into the teaching of GD&T and CAD modeling allows the student to conceptualize the part from the design to manufacturing to final inspection, which should result in part designs that are more suitable to manufacturing.

It is common for instructors of modeling courses to emphasize the importance of "capturing design intent." To "capture design intent" means, "to capture the designers intent for manufacturing and inspecting the part so as to end up with a functional design." Assignments should require that students not only model the part, but also model the fixtures for holding the part during the manufacturing process, as well as the gages that would be used for inspection of the part. This assignment would require the student to think through the entire design, manufacturing, and inspection loop as well as reinforce the design for manufacturability concept.

**Eliminate the Single Component Pitfall**

Far too often modeling assignments are made that require the students to model a single complex component part without the benefit of understanding how the part is to function when incorporated with mating parts. If we are to teach GD&T (functional dimensioning) and design for manufacturability (design of functional parts), it is imperative that students understand how the part inter-relates with mating parts. Without this understanding, it is not possible for GD&T to be properly applied and the concept of designing for manufacturability will be lost.

This does not mean that large assemblies are required. In fact, students can more readily grasp the concept of functionality by using simple models and small assemblies. The instructor can also assign a single component and teach functional design by providing an explanation of how a single component inter-relates mating parts, without requiring completion of an entire assembly.

**Using Datums to Develop the Design for Manufacturability Mentality**

By applying GD&T it is intended that the design will communicate precisely to the manufacturing entity how the part is to be made and then to inspection entity how the part is to be inspected. The result is functional parts that meet the intent of the designer. In essence, what is required is consistency in the understanding of the design from the creation of the model through final inspection of the part.

By requiring students to identify the datum reference frame on their model and then to be consistent with the application of location dimensions both in the model and the draft views the instructor can reinforce the idea of being consistent with regard to the design. For example, take a block that has two thru holes.

- Require students to display the primary, secondary, and tertiary datums. Colors can be used to differentiate them.
- Require students to add a note on a layer within the models to indicate if they are considering the two holes as two independent holes or as a pair of holes. If the holes are independent, they should be modeled as two holes. If the holes are a pair of holes, they should be modeled as an array. The student is required to stipulate their concept of the design and then demonstrate their understanding of their concept by the way in which they model the part.
- When locating the holes, require students to locate the hole from the datums and not just from any edge. In terms of the model, there may be no difference. However, by requiring

the student to show the datums and then to utilize them in developing the model, the student is forced to deal with the issue of consistency in their designs.
- If dimensioned drafts (2D drawings) of the model are developed, require that the dimensions be consistent with both the model and the established datums.

If our goal is to capture design intent in order to have consistency from design to inspection, it only makes since that we should insist on this consistency within the model and dimensioned drafts.

## The Importance of Sketching

A good design engineer considers all aspects of design simultaneously, including how it will be manufactured, even when just sketching out the conceptual idea. A product can function smoothly as an integrated system only if design decisions are made in an integrated fashion.[5] To this end, there is a trend in engineering design graphics to increase emphasis on freehand sketching. This is appropriate, as sketching is a critical communication and thinking tool during conceptual design.[3]

Sketching allows us to communicate ideas with only a marking tool and a surface on which to mark. We may be sketching on a napkin with a pen, on a palm with a stylus, or some other means that we can not yet imagine. The speed at which we can communicate with a freehand sketch means this skill will be required well into the future. The instructor should emphasize that sketches are to be freehand, without straightedges or instruments, in order to reap the full benefits of speedy communication.

## Suggested Course Content

The following outline provides suggested content for developing students' skills in technical graphics and geometric dimensioning and tolerancing while simultaneously providing a basic understanding of manufacturing and inspection.

- First Semester
    - Freehand isometric sketching
    - Freehand orthographic sketching
    - 3D modeling techniques
    - Sections
    - Auxiliary Views
    - Fasteners
    - Coordinate Dimensions
    - Working Drawings

It is apparent that many of these topics are similar, to a classical technical graphics course using manual drafting or 2D CAD. However, it is recommended that the material be taught by going from 3D to 2D rather than 2D to 3D.

- Second Semester
  - Geometric Dimensioning & Tolerancing
  - Dimensioning as a System
  - Fixtures and Gages

The second course should use GD&T as the foundation of the course. The instructor is encouraged to use simple models. By using simple models, students will better understand the abstract dimensioning concepts and will better be able to apply rudimentary fixturing and gaging rules.

**Conclusion**

Incorporation of three-dimensional modeling and geometric dimensioning and tolerancing into technical graphics courses allows us to develop students' understanding of the manufacturing and inspection processes. By providing an understanding of the relationship of design, manufacturing, and inspection, our students will better understand the importance of communicating design (manufacturing) intent and a consistent interpretation through out the design/manufacturing cycle.


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