Datum Reference Frame Applications in a Senior-Level, Engineering Technology Capstone Course

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Abstract

Many engineering graphics instructors introduce students to the principles of GD&T using a wide variety of pedagogical methods. Perhaps the logical starting point for teaching GD&T is the selection and use of a datum reference frame (DRF), which is the theoretical frame of reference established by real part features. This paper will describe how instructors of a senior-level capstone course at Illinois State University guide students through the process of selecting and using datum reference frames during the manufacture of products in a student-designed lean production cell. Good and bad examples of student projects having a focus on the consistent application of datum reference frames will be discussed.

Introduction

The key concept in geometric dimensioning and tolerancing (GD&T) is the datum reference frame (DRF) (Neumann & Neumann, 2009). The DRF consists of three mutually perpendicular axes and planes, which intersect to establish the DRF origin. The DRF is the key form of communication between the design, manufacturing, and inspection processes. This paper describes how instructors of a senior-level capstone course at Illinois State University guide students through the process of selecting and using datum reference frames during the manufacture of products in a student-designed lean production cell.

Since all geometric dimensions and specifications are related to the DRF, it is an effective tool to coordinate design, fabrication, inspection, and assembly of products. Within this system, it is key that a designer strategically identify features on a part as datum features to establish relationships specified by the geometric tolerances and to also constrain the part within all degrees of freedom (ASME, 2009; Madsen & Madsen, 2013).

A common mistake that educators make when covering GD&T is only talking about it within the context of a single part. In order for students to fully understand GD&T

concepts, especially the DRF, it is crucial that they work with assemblies of parts (Leduc, 2002). It is also important that students interact with GD&T ideas in multiple ways. Waldorf & Georgeou (2016) discuss the use of Bloom's Taxonomy to integrate GD&T throughout a manufacturing engineering curriculum. They list several ways of covering DRF concepts (pp. 7-8):

- ***Application:*** Associate product functional requirements with the assignment of datums on drawings.
- ***Analysis:*** Relate geometric tolerances to datums and datum reference frames.
- ***Synthesis:*** Plan and construct a solid CAD model and a part drawing with datums, datum refinements, and location tolerances; Formulate a strategy for location tolerancing to ensure interchangeability of parts; Improve a design to make it easier to fixture, produce, or inspect; Design a production fixture for an operation based on part drawing; and Design an inspection process for a part based on part drawing.
- ***Evaluation:*** Compare fixturing and inspection alternatives for features or datums that are referenced at MMC.

Course Description

The engineering technology senior capstone course at Illinois State University focuses on the study of industrial production systems including product, manufacturing, and plant engineering through managing a production project in the university's manufacturing lab. In the course, students divide into teams of five with members having a variety of technical roles to develop and implement a lean production process. The 16-week course includes six graded milestone submissions that allow the instructor to evaluate the progress of the teams using formative assessment methods. Table 1 shows the six project milestones and the associated point values for grading purposes. The focus of this paper will be on the GD&T related activities included in milestones 2 (product design) and 3 (fixture design & fabrication) undertaken by a team of students charged with the task of designing and manufacturing the tape dispenser product shown in figures 1 and 2. Of the 12 component parts illustrated in figure 2, four of the parts (items 1, 2, 6 & 8) are shop-made components with the remaining items being standard parts that are purchased.

Table 1. Project Milestones.

Milestone	Grade Weight	Description of Milestone Contents
Milestone 1: Team Charter	20 points	• Rules to govern group interaction, Project WBS, Project PERT and Gantt charts
Milestone 2: Product Design	100 points	• CAD models and part drawings, manufacturing process plan, material flow, build a prototype to evaluate, compute prototype cost
Milestone 3: Fixture Design & Fabrication	200 points	• Design & fabrication of fixtures, PERT and cost, Control Plan needed to make product with repeatable accuracy, process plan for LEAN production • First Article Inspections (FAI) – make 1 product from fixtures and verify fixtures make quality parts.
Milestone 4: Pilot- run	100 points	• Kanban, work instructions • Pilot Run: make 2 products using fixtures
Milestone 5: Production Run	100 points	• Make products.
Milestone 6: Project Closeout	30 points	• Submit PPAP and presentation of project results

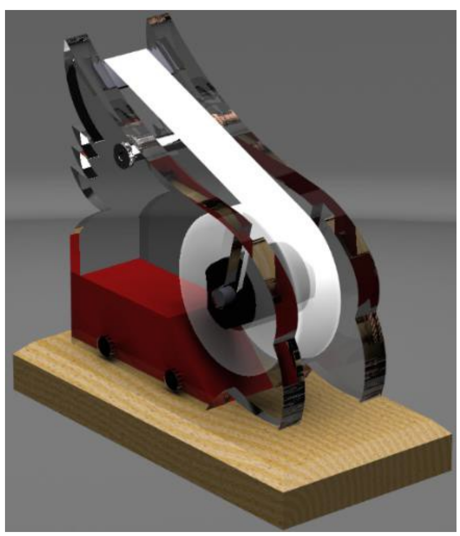
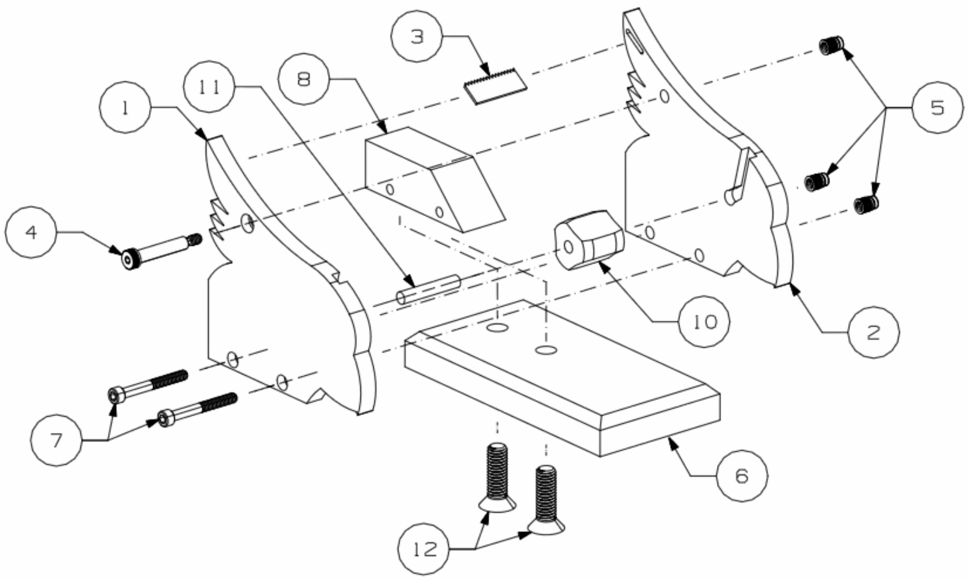


Figure 1. Tape Dispenser Project.



12	FLAT_HEAD_MACHINE_SCREW_1.25_LONG	2
11	TAPE_SPOOL_SHAFT	1
10	TAPE_SPOOL	1
9	TAPE	1
8	BASE_SPACER_BLOCK	1
7	SOCKET_HEAD_CAP_SCREW	2
6	BASE	1
5	THREADED_INSERT	3
4	SHOULDER_SCREW	1
3	CUTTER_BLADE	1
2	REGGIE_LEFT	1
1	REGGIE_RIGHT	1
PC NO	PART NAME	QTY

Figure 2. Tape Dispenser Exploded View and Parts List.

At the beginning of the course, students were given paper-based concept drawings with nominal dimensions (i.e. no tolerances) of the tape dispenser product that was modeled after “Reggie”, the university mascot. As part of Milestone 2, the students were instructed to model the tape dispenser product using “appropriate” modeling tools in the NX CAD system used at the university. In addition to creating CAD models of the project, students also built a prototype tape dispenser using the machine tools in the manufacturing lab. Prior to building the prototype, the students were told it was important that the product be easy to assemble and that the back surface of the Base Spacer Block should be flush with the back faces of the two vertical component parts called “Reggie Left” and “Reggie Right” (see Figures 2 & 3). While building of the prototype product, students were able to identify the component part features that have a direct impact on product assembly and quality. The students determined the hole features identified by dark arrows in Figure 4 were very important and needed to be controlled dimensionally using GD&T. Students correctly determined that in order for the three flat surfaces to be flush when assembled, these holes must be located relative to the datum surfaces illustrated in Figure 4.

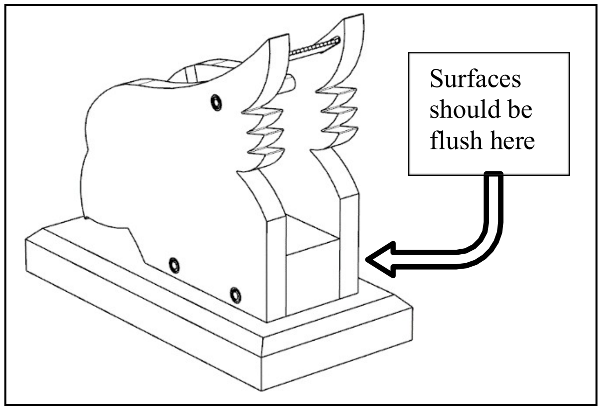


Figure 3. Important Assembly Concern.

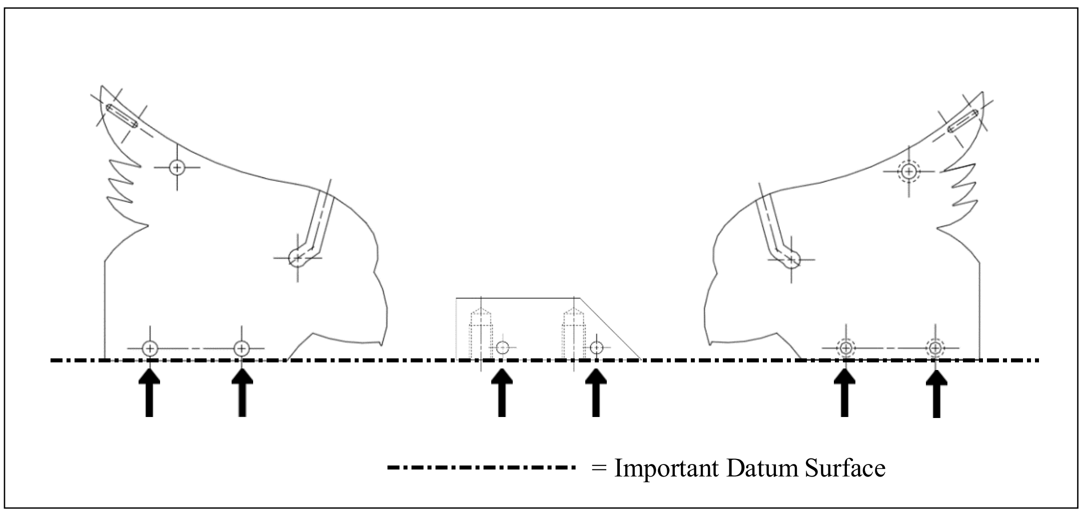


Figure 4. Important Hole Locations on Three Components.

Determining Datum Reference Frames

After the students determined that the holes identified in Figure 4 are important part features in the tape dispenser product, their task was to decide the best GD&T tools to use to control the features appropriately. An important part of this task was the identification of the datum features that the hole locations should reference. The phantom lines in Figure 4 illustrate the datum edges that were identified by the students. The next task was to use these datum features to create a datum reference frame on each of the three parts. Figure 5 illustrates the datum reference frame created for each of the three parts.

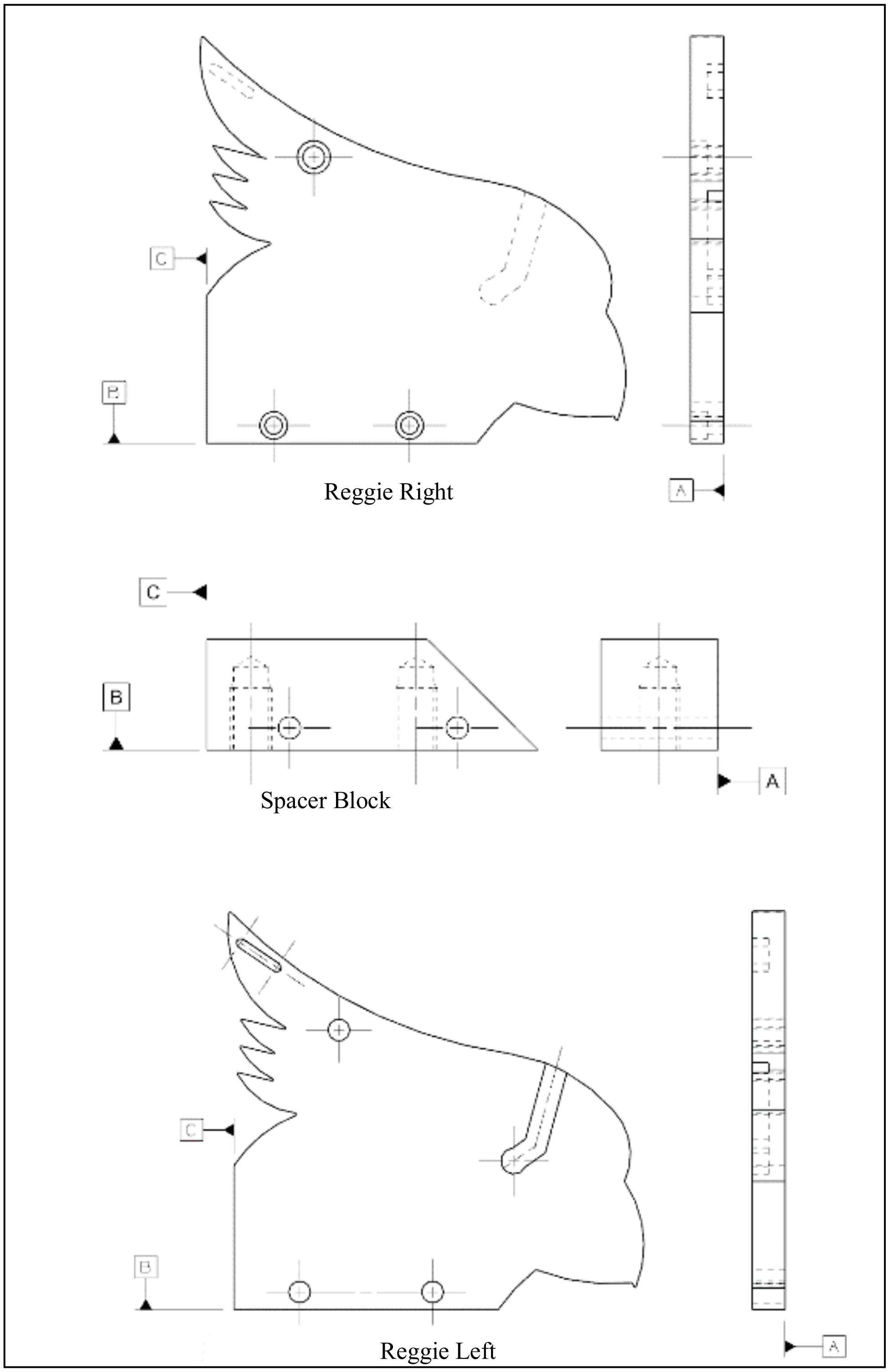


Figure 5. Datum Reference Frames for Parts.

After the datum reference frame was annotated, the feature control frames for the hole features were created. On this project, the position tolerance was used to locate the holes. Position was used because it is intended to locate center points and axes for features of size. The order of datums referenced in the feature control frame was carefully considered by the students because they determine the machining and inspection setups that must be used during production. Figure 6 shows the parts with the feature control frames added.

The datum features were then labeled on the prototype to help the students see the correlation between datum identifiers and the actual features on the physical product. After the product design and prototype were complete, they were submitted for evaluation at part of Milestone 2.

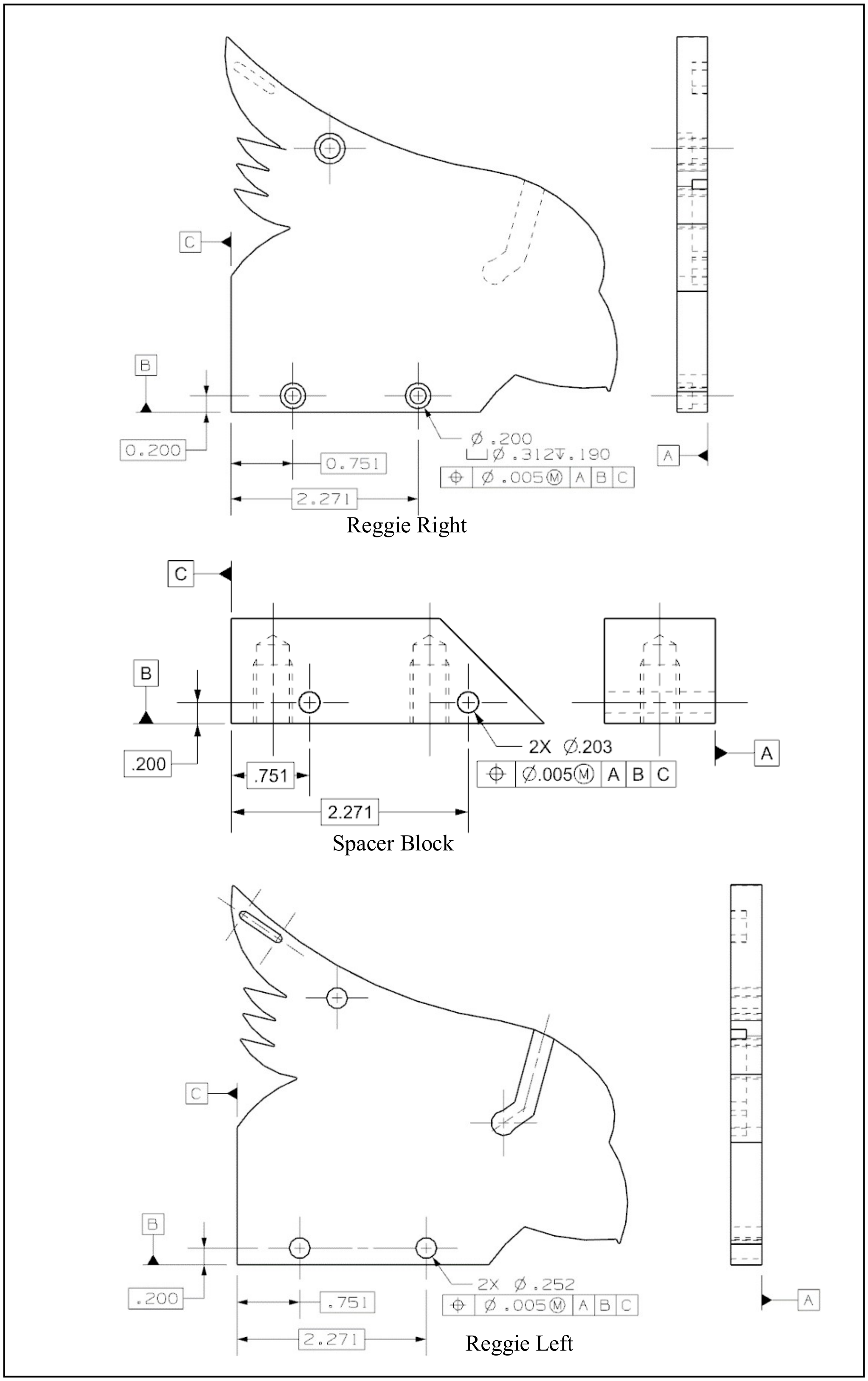


Figure 6. Feature Control Frames for Holes.

Fixture Creation

The machining fixtures used to hold the workpieces during machining were designed and built next. Considerable attention was paid to the order of precedence of datums in all feature control frames. The order of precedence of the datum features listed in the feature control frame dictates the part locating methodology used in the workholding devices. In the student-designed fixture illustrated in Figure 7, the first (primary) datum feature to be placed on the fixture is Datum A (a large flat face of the part), which is placed flat against the upper surface of the fixture base.
The second datum feature to be used is Datum B, which is placed touching 2 locator pins on the fixture. The final datum feature to be used, Datum C, is placed touching the third locator pin.

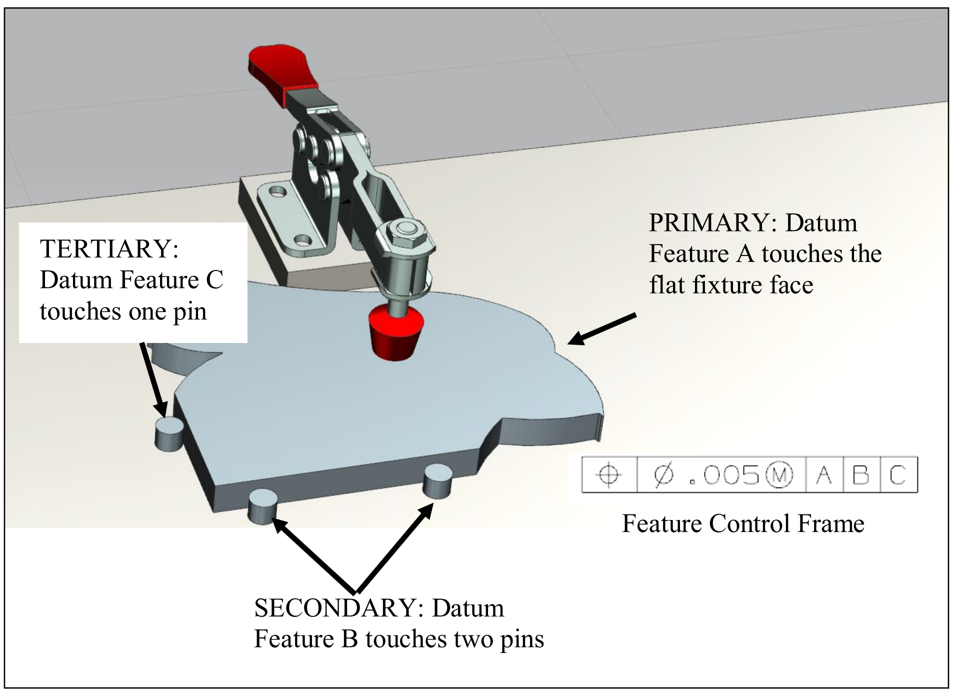


Figure 7. Part Location on Fixture.

Common Student Errors

It is not uncommon for students to design fixtures seemingly without regard for the datum reference frame. The use of the primary, secondary, and tertiary datum features in a feature control frame dictate the manner in which a part should be located on a workholding device. Changing the order that datum features are listed in a feature control frame will often require a new fixture be created in order to locate the workpiece using the specified datum reference frame. This can be an eye-opening experience for students when they learn that they must design and build additional fixtures because of the datum reference frame used in feature control frames. Figure 8 illustrates an example where the feature control frame calls for datum feature A to be placed down on the fixture first, but the fixture incorrectly has datum feature A facing away from the fixture.

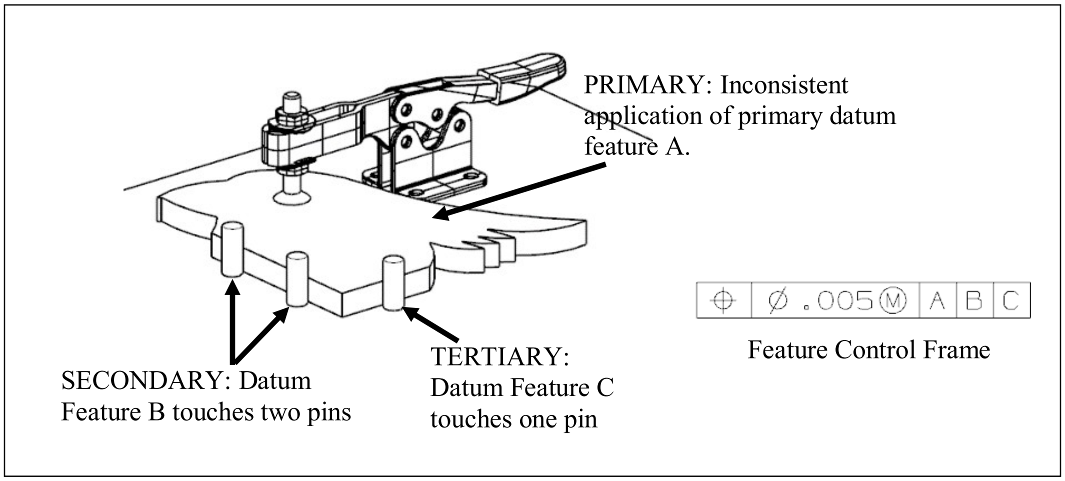


Figure 8. Inconsistent use of DRF in Fixture Design.

Another example of a common student error occurs when a feature control frame is added to control the shape and location of the slot on the Reggie-right part. Because the slot and counterbore features are on opposite faces of the part, two machining setups are required.

Students often fail to recognize that multiple machining setups requires the creation of another DRF. Figure 9 shows the Reggie-Right part with datum D and profile of a surface feature control frame added for the slot feature. The fixture shown in Figure 8 could be used to hold the part when machining the slot as dimensioned in Figure 9.

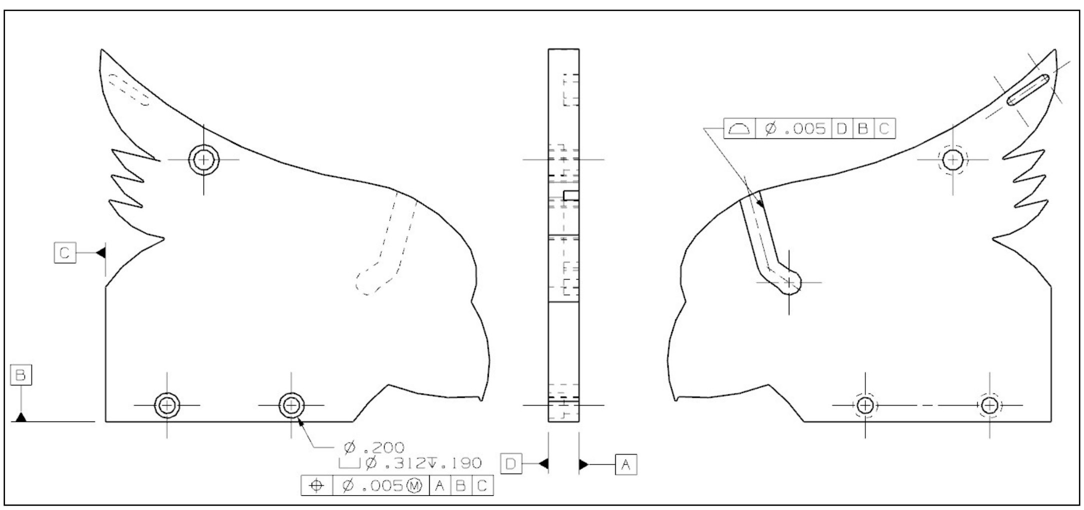


Figure 9. Additional Datum Feature for Second Machining Setup

Conclusions

In order for students to have a deep understanding of GD&T concepts, especially the

DRF, it is important that they work with assemblies of parts. It is also important that students interact with GD&T ideas in multiple ways. The engineering technology capstone course at *institution name* requires students to apply GD&T concepts within the context of a semester-long design & manufacturing project. Students work in teams to analyze the relationships among component part features in a product. After physically building the product, students identify those features that are most important to ensure quality and ease of assembly. Students then use the datum reference frames during the manufacture of the product. This process provides unique learning opportunities for students that they would not experience with a "design-only" project. Fixtures designed and created based on an appropriate datum reference frame typically yield good assembly fits. Poor datum reference frame selection and fixtures created inconsistent with the datum reference frame usually result in parts not assembling properly. The role of the instructor in this process is to give feedback to students at major milestones in the process and also guide them through the problem- solving process when things go wrong.

References

ASME (2009). *Dimensioning and Tolerancing, ASME Y14.5-2009*. NY: American Society of Mechanical Engineers. 2009. ISBN 0-7918-3192-2.

Leduc, A. M. (June, 2002). 3-D modeling/GD&T – Cornerstones for manufacturing education.

Proceedings of the 2002 Annual Meeting of the American Society for Engineering Education, Montreal, Quebec, Canada, June 16-19, 2002.

Madsen, D. A., & Madsen, D. P. (2013). *Geometric dimensioning and tolerancing* (9^{th} ed.). Tinley Park, IL: Goodheart-Wilcox Publisher.

Neumann, S., & Neumann, A. (2009). *GeoTol Pro: A practical guide to Geometric Tolerancing*.

Longboat Key, FL: Technical Consultants, Inc.

Waldorf, D. J., & Georgeou, T. M. (June, 2016). Geometric dimensioning and tolerancing (GD&T) integration throughout a manufacturing engineering curriculum. *Proceedings of the 2016 Annual Conference of the American Society for Engineering Education, New Orleans, Louisiana, June 26-29, 2016.*