Students' Understanding of Datum Reference Frame Concepts in a GD&T Course: Student Outcomes Across Multiple Semesters

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Abstract

TEC333-Geometric Dimensioning & Tolerancing addresses two of the overall program outcomes in the Engineering Technology program at Illinois State University. These outcomes include utilizing 2-D and 3-D computer-aided design systems to create drawings and models for products, machines, jigs, fixtures, and other mechanical devices used in manufacturing environments and being able to read and interpret manufacturing documentation such as blue prints, technical drawings and diagrams, production plans, tooling plans, quality plans, and safety plans. One of the key outcomes of TEC333 is that students can apply appropriate datum reference frames to designs. Students are asked to demonstrate their understanding of the datum reference frame concepts in several ways throughout the course on a pretest, tests, online quizzes, modeling & drawing assignments, measuring assignments, and the final exam. Specific examples include labeling a datum reference frame origin on a given drawing, sketching datum feature symbols on a drawing given sentence descriptions of the datums, identifying established datums when given a drawing, modeling parts with the datum reference frames consistent with the datum reference frame on a given drawing, and designing datum reference frames for parts within a given assembly. This paper will present ways students are assessed on datum reference frame topics, present the results of these assessments over the last several years, and provide recommendations for future work.

Introduction / Review of Literature

TEC333 was added to the Engineering Technology program in the Fall of 2016 as a technical elective at the urging of the program's industrial advisory board. Since that time the course has been taught each fall semester to provide students with an overview of the basic terminology used in GD&T, opportunities to apply GD&T in a design setting for modestly complex parts, activities where students can apply GD&T within a CAD environment, and laboratories where students inspect parts using calipers and coordinate measuring machines (CMM). *GeoTol Pro: A Practical Guide to Geometric Tolerancing per ASME Y14.5 – 2009* [1] and ASME Standards for *Dimensioning & Tolerancing* [2] are the main resources used in the course.

A key learning outcome of this course and of the Engineering Technology program is that students be able to apply appropriate datum reference frames (DRF) to designs. To be successful, DRF concepts need to be introduced and applied in many ways and at different levels of complexity. Waldorf and Georgeou discuss integrating GD&T concepts throughout a manufacturing curriculum by designing assessments at different cognitive levels of Bloom's taxonomy [3]. They specifically mention the importance of designing assignments where students must exercise cognitive processes in application, analysis, synthesis, and evaluation.

DRF Assessments within TEC333

Over the past four fall semesters, students have consistently been assessed on their understanding of topics within TEC333. Assessments included a pretest, two tests, a final exam, weekly online quizzes, and laboratory assignments. Questions within the quizzes, tests, and exam were developed to assess students' understanding of DRF concepts at multiple levels of Bloom's

Revised Taxonomy [4]. Items and activities were designed to assess learning under the process categories of Remember, Understand, Apply, Analyze, Evaluate, and Create. Figures 1-5 illustrate some of the assessments used in the course. Figure 1 shows an example item from the pretest where students are asked to clearly label the DRF origin in both views. This illustrates an item at the revised Bloom's Apply-Implementing cognitive level. Here the student correctly labeled the origin in the front view but incorrectly labeled the origin in the right-side view.

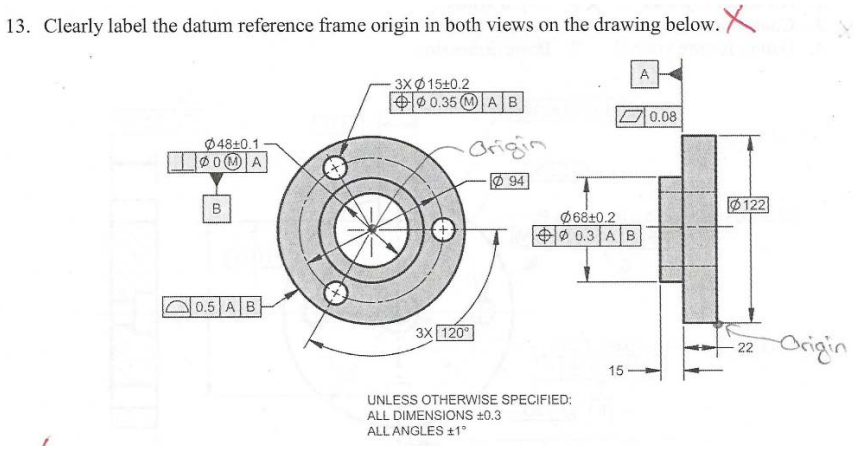


Figure 1. Labeling the DRF Origin
Bloom's Category: Apply-Implementing [1].

The items in Figure 2 illustrate the revised Bloom's cognitive level of Understand-Interpret. Here students are required to take a sentence description of a datum feature and sketch the datum feature symbol in the appropriate location on the correct view. In this case the student only received credit for item 15 (although the student did not leave the required visible gap between the extension line and the visible line). The datum feature symbols for datums B, C, & D were not placed correctly.

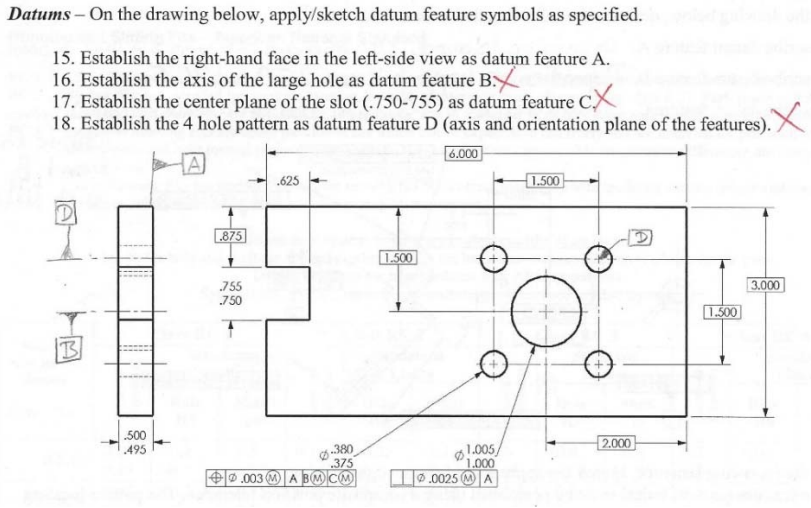
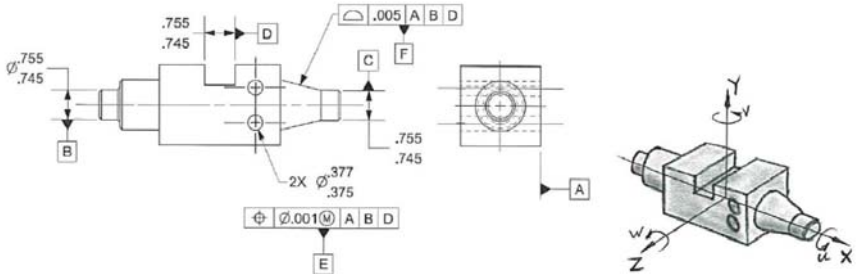


Figure 2. Sketching Datum Feature Symbols
Bloom's Category: Understand-Interpreting.

The example in Figure 3 illustrates items at two different cognitive levels of the revised Bloom's taxonomy. First students must Remember-Recognize by identifying the established datum. In the example, the primary datum feature A is identified by the datum feature symbol in the right-side view. The student must recognize that the established datum, in this case, is a "Plane". When filling in the columns for the constrained degrees of freedom, students must execute the cognitive level of Evaluate-Critiquing. Datum A constrains translations only in the "z" direction, and it constrains rotations about the X and Y axes (or in the "u" and "v" direction).



Primary Datum Feature		Established Datum	Constrained Degrees of Freedom	
			Translations (x,y,z)	Rotations (u,v,w)
	A	Plane	z	u,v
17.	B - C	Axis	Y Z 1	V ~~X~~, W 2
18.	D	Center plane	X 1	V, W 2
19.	E	Axis & 2 planes	X, Y 2	U, V, W 2
20.	F	Axis & plane	X, Y, Z 3	~~X~~ V, W 3

Figure 3. Identifying Datums and Constrained Degrees of Freedom Bloom's Categories: Remember-Recognize and Evaluate-Critiquing.

Figures 4 & 5 show work from the last assignment of the semester. Students were given a ROBOT END OF ARM TOOLING (EOAT) PLATE and a basic drawing of the part (Figure 4). Students were required to determine the design intent of the part, and then plan strategies for applying the GD&T, modeling the part, and inspecting the part. These activities are at the highest end of the revised Bloom's taxonomy and can be classified as Create-Producing.

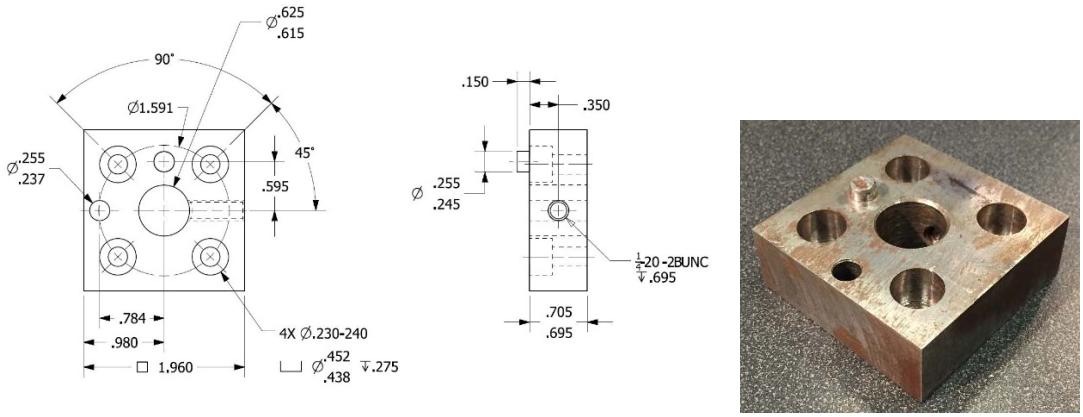
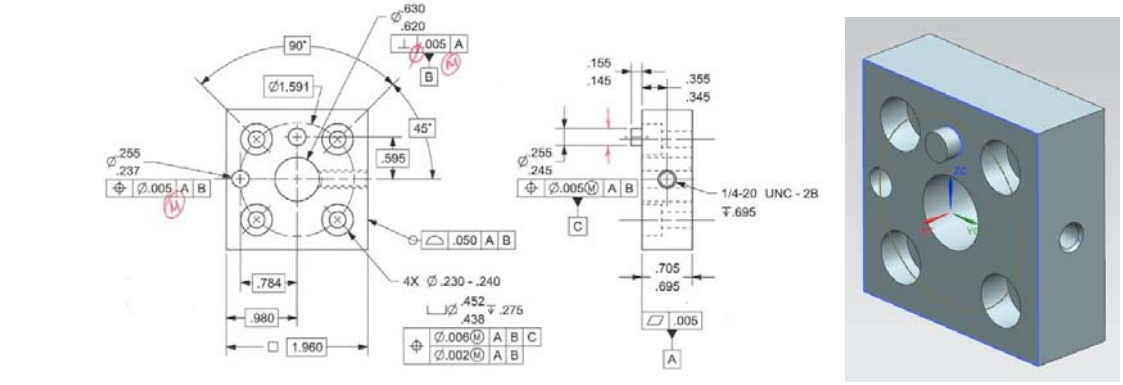
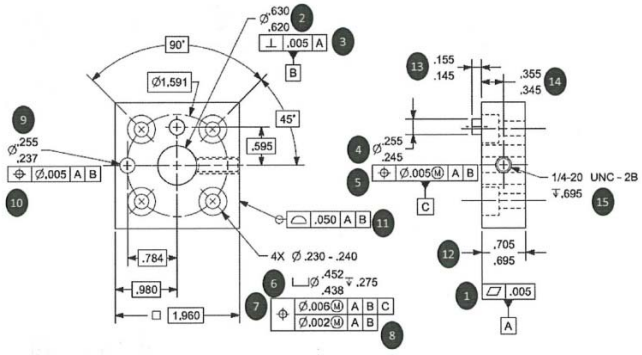


Figure 4. LAB 13 – ROBOT EOAT PLATE.





Item Number	Inspection Requirements	# OF POINTS?	Reporting Method	Equipment or Gage	Actual
1	Check Flatness DATUM A		Pass/Fail	Brown and Sharpe	.0001
2	Check Diameter DATUM B		Pass/Fail	Brown and Sharpe	.6265
3	Check Perpendicularity DATUM B		Pass/Fail	Brown and Sharpe	.0005
4	Check Diameter DATUM C		Pass/Fail	Brown and Sharpe	.2507
5	Check Position DATUM C		Pass/Fail	Brown and Sharpe	.0079
6	Check Diameter of All Holes COUNTER BORE		Pass/Fail	Brown and Sharpe	All Pass
7	Check Position SHOULD BE ONE COMPOSITE POS. CHECK		Pass/Fail	Brown and Sharpe	Hole 3 pass
8	Check Position		Pass/Fail	Brown and Sharpe	Hole 3 pass
9	Check Diameter		Pass/Fail	Brown and Sharpe	.2368
10	Check Position		Pass/Fail	Brown and Sharpe	Hole fail, no position check

#2 Tolerance Report						
Feature	DATUM_A					
Type	PLANE					
	Nom	Act	Dev	LoTol	UpTol	OutTol
FLAT			0.0001		0.0050	

#3 Tolerance Report						
Feature	DATUM_B					
Type	CYLINDER					
SubType	INNER					
	Nom	Act	Dev	LoTol	UpTol	OutTol
DIA	0.6250	0.6265	0.0015	-0.0050	0.0050	

#4 Tolerance Report						
Feature	DATUM_B					
Type	CYLINDER					
SubType	INNER					
	Nom	Act	Dev	LoTol	UpTol	OutTol
PERP_YZ			0.0005		0.0050	
	Datum1	DATUM_A				

Figure 5. LAB 13
Bloom's Category: Create-Producing.

Data, Analyses, and Results

As mentioned earlier, this course has been offered each fall since 2016. Table 1 shows enrollment numbers in each of the last four years, and it also displays some demographic information on the students who were enrolled.

Table 1. DRF Assessment Items and their Revised Bloom's Category.

Semester	Fall 2016	Fall 2017	Fall 2018	Fall 2019	TOTAL
Total Enrollment	12	19	10	11	**52**
Undergraduate	10	17	10	11	**48**
Graduate	2	2	0	0	**4**

In addition to the earlier examples, there were over 30 other occasions where students were assessed on DRF concepts. To get a better understanding of how students performed on these assessments, data was gathered over the last four years. Table 2 gives a description of the items and their category from the revised Bloom's Taxonomy. The table also shows the percentage of students who correctly answered the items or fully satisfied the assignments.

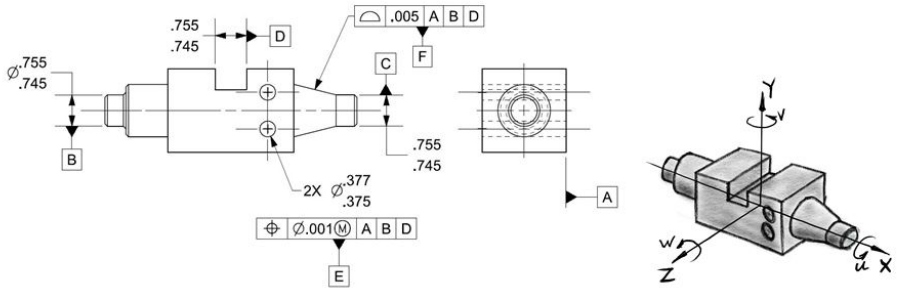
Table 2. DRF Assessment Items and their Revised Bloom's Category.

Assessment	Item	Revised Bloom's Category	% Correct
Pretest – 13	Label the DRF Origin in both views.	Apply – Implementing	0%
Pretest – 15	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	50%
Pretest – 16	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	29%
Pretest – 17	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	4%
Pretest – 18	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	25%
Test 1 – 38	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	79%
Test 2 – 4	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	90%
Test 2 – 5	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	90%
Test 2 – 6	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	69%
Test 2 – 7	Sketch the Datum Feature Symbol given a description.	Understand – Interpreting	98%
Test 2 – 8	Sketch the Datum Feature Symbols given a scenario.	Apply – Implementing	25%
Test 2 – 17	Identify the datum based on a given drawing.	Remember – Recognize	85%
	Determine constrained DOF of datum.	Evaluate – Critiquing	20%
Test 2 – 18	Identify the datum based on a given drawing.	Remember – Recognize	75%
	Determine constrained DOF of datum.	Evaluate – Critiquing	50%
Test 2 – 19	Identify the datum based on a given drawing.	Remember – Recognize	50%
	Determine constrained DOF of datum.	Evaluate – Critiquing	37%
Test 2 – 20	Identify the datum based on a given drawing.	Remember – Recognize	48%
	Determine constrained DOF of datum.	Evaluate – Critiquing	42%
Exam – 1	Sketch the Datum Feature Symbols given a scenario	Apply – Implementing	29%
Exam – 3	Sketch the Datum Feature Symbol given a description	Understand – Interpreting	92%
Exam – 17	Label the DRF Origin in both views.	Apply – Implementing	60%
Exam – 18	Label the DRF Origin in both views.	Apply – Implementing	58%
Exam – 21	Label the DRF Origin in both views.	Apply – Implementing	38%
Exam – 22	Identify the datum based on a given drawing.	Remember – Recognize	100%
	Determine constrained DOF of datum.	Evaluate – Critiquing	81%
Exam – 23	Identify the datum based on a given drawing.	Remember – Recognize	96%
	Determine constrained DOF of datum.	Evaluate – Critiquing	62%
Exam – 24	Identify the datum based on a given drawing.	Remember – Recognize	79%
	Determine constrained DOF of datum.	Evaluate – Critiquing	56%
Exam – 25	Identify the datum based on a given drawing.	Remember – Recognize	85%
	Determine constrained DOF of datum.	Evaluate – Critiquing	48%
Exam – 26	Identify the datum based on a given drawing.	Remember – Recognize	90%
	Determine constrained DOF of datum.	Evaluate – Critiquing	75%
LAB – 3	Create a 3D CAD model where the origin is consistent with the DRF origin on the drawing.	Create – Planning	33%
LAB – 5	Inspection order is consistent with the DRF order (precedence) on the drawing.	Create – Planning	38%
LAB – 9	Create a 3D CAD model where the origin is consistent with the DRF origin on the drawing.	Create – Planning	35%
LAB – 11	Create a 3D CAD model where the origin is consistent with the DRF origin on the drawing.	Create – Planning	85%
LAB – 13	Design a dimensional measurement plan. Make the model origin and DRF origin on the drawing consistent.	Create – Producing	44%

Table 2 revealed some interesting results. One might expect items on a pretest would have a low number of students answering them correctly since most of the material on the pretest is not covered in prerequisite courses. The tests, final exam, and laboratories were designed to assess the material covered in class up to that point in the semester. In general, students appeared to perform better on items that required them to Remember, Understand, or Apply than on items which required them to Analyze, Evaluate, or Create. To help understand students' performances better, several specific assessment items will be evaluated. Table 3 displays the correct response percentages for each cell in the table over the past four fall semesters (refer to Figure 3 for the original problem).

Table 3. Correct percentages from item requiring Remember-Recognize and Evaluate-Critiquing.

Datum Features – Given the following illustrations, complete the table below *(3 points each)*.



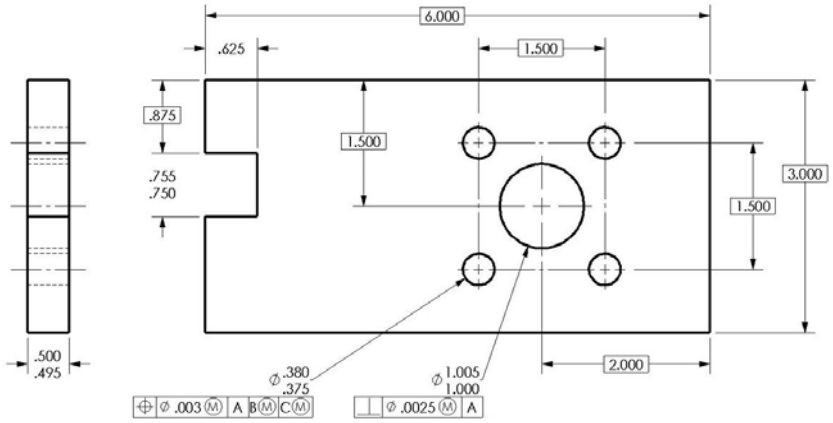
Primary Datum Feature		Established Datum	Constrained Degrees of Freedom	
			Translations (x,y,z)	Rotations (u,v,w)
		% Correct	% Correct	% Correct
17.	**B - C**	85%	62%	63%
18.	**D**	75%	63%	60%
19.	**E**	48%	50%	52%
20.	**F**	48%	50%	65%

Students were able to identify the established datums for items 17 (axis) & 18 (center plane) at a much higher rate than items 19 (2 holes, axis & two planes) & 20 (conical, axis & plane). This is likely due to differences in the complexity of the geometry. Percentages for correctly identifying the constrained degrees of freedom were all low (65% or less). Again, these items required a higher level of cognitive processing than identifying the datums.

Table 4 shows the results from questions at the Understanding-Interpreting cognitive level. These 4 items required students to sketch the datum feature symbol when given a sentence description of the datum feature. Students did well sketching datum feature symbols for a plane,

an axis of a hole, and a pattern of holes. They did not do as well when they were required to sketch a datum feature symbol for a center plane.

Table 4. Correct percentages from item requiring Understanding-Interpreting.



Item	% Correct
Establish the right-hand face in the left-side view as datum feature A.	90%
Establish the axis of the large hole as datum feature B.	90%
Establish the center plane of the slot (.750-.755) as datum feature C.	69%
Establish the 4-hole pattern as datum feature D.	98%

The laboratory assignments in the class required students to put previous concepts covered in the course into action (Create-Planning). Figure 6 shows an example of one of the assignments in the course where students were required to create a 3D model of the SWITCH COVER and then generate a drawing with all the required geometric tolerancing. The origin of the 3D model needed to be consistent with the origin of the DRF. Students also had to ensure symmetry was maintained when model dimensions were modified.

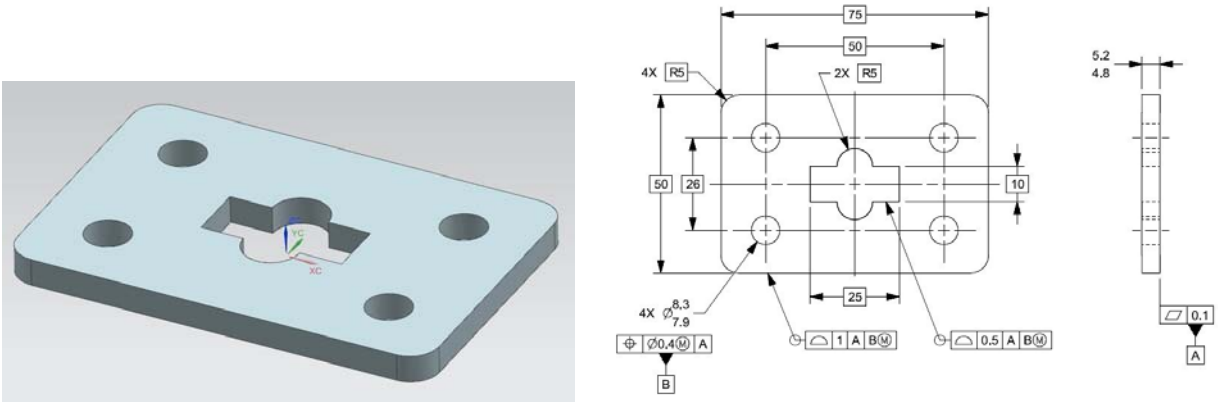


Figure 6. LAB 11 – Create-Producing.

For this activity, 85% of the students maintained consistent origins between the 3D model and the specified DRF on the drawing. The percentage was much lower for the ROBOT EOAT

PLATE in LAB 13 (see Figures 4 & 5). Only 44% of students had consistent origins between the 3D model and the specified DRF on the drawing.

Conclusions

The concept of datum reference frame must be understood to execute geometric dimensioning and tolerancing within design, manufacturing, and inspection environments. It is clear from the assessment results from TEC333 that students understand certain aspects of the DRF better than others. In general, the data appear to indicate students correctly answered test and final exam items at the Remember, Understand, and Apply levels of Bloom's taxonomy better than at the Analyze, Evaluate, and Create. The data do indicate that emphasis needs to be placed on the following activities in the course.

Sketching datum feature symbols to indicate the center plane of a slot. Only 67% of students correctly sketched the datum feature symbol in line with the dimension of the slot on the second test. The rest of the students placed the datum feature symbol somewhere else on an extension line of the slot dimension.

Identifying and labeling the DRF origin on a drawing given the datums. There were three items on the final exam which required students to correctly label the datum reference frame origin on a given drawing (correctly answered by 60%, 58%, and 38% of students).

Identifying the geometry associated with a datum and identifying the degrees of freedom that the datum constrains. More practice is needed identifying datums for conical shapes and patterns of holes. When datums were correctly identified, many students struggled to identify the translational and rotational degrees of freedom that the datums constrained. This activity requires good spatial visualization skills, and it may be that a lack of spatial skills contributed to the poor response rates.

Sketching datum feature symbols on a drawing when given a design scenario for the part. Only 25% of students correctly answered this item on the second test and 29% answered it correctly on the final exam. There was a great degree of variability between semesters for these items (9%-50% on the second test and 18%-50% on the exam). Other factors such as spatial visualization ability and familiarity with machine parts might have contributed to the variability.

Creating consistent origins between a 3D model and the DRF origin on the drawing. The modeling strategies of students varied greatly for the laboratory activities. Many students did not consider the impact of their model origin if the values of dimensions needed to be modified. Industry professionals might argue that it is not important for model origins to be consistent with the DRF origins of a drawing. This was emphasized for educational purposes within the course to help students visualize coordinate systems and to think about the impact of these coordinate systems on design, manufacturing, and inspection activities. Analyzing models, drawings, dimensional measurement plans, and inspection reports from the last assignment in the course also revealed the need to put more emphasis on consistent coordinate systems between these areas. Only 44% of students created consisted datum reference frames between the required documents for this assignment.

Future Research

This initial investigation of DRF concepts in TEC333 revealed several potential future research activities. Students did not perform well when asked to identify the constrained degrees of freedom for a particular type of datum. This might be influenced by factors such as spatial visualization ability. Future work might involve examining the relationship between a student's spatial ability and their ability to identify constrained degrees of freedom. Similarly, some students may understand the DRF symbols but struggle to associate DRF features on a part drawing to those on a physical part. The tactile aspect of handling the physical parts illustrated in part drawings may help students develop a better understanding of DRF concepts.

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