Laboratory Measurement Activities in a First-Year Engineering Technology Class

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Abstract

Purdue Polytechnic Columbus is one of ten statewide extensions of Purdue University and is located about an hour south of Indianapolis in an economic region dominated by manufacturing. Just less than 40% of the workforce in this 10 county region is directly employed by the manufacturing industry. The primary employer in the region is diesel-engine manufacturer Cummins, Inc. but there are many others including Toyota, Honda, Faurecia, NTN Driveshaft, Valeo, and Aisin. Most of the manufacturing industry is related to automobile production. Purdue Polytechnic Columbus is unique among higher education institutions due to a partnership with diesel-engine manufacturer Cummins Inc. that has led to an environmentally-controlled metrology lab located within the university facility. The lab contains a calibrated coordinate measuring machine, calibrated tensile tester, a surface finish instrument, a roundness tester and a plethora of donated hand tools including calipers, micrometers, height gauges, bore gauges, PI tapes, sine blocks, and several sets of gauge blocks.

The challenge has been to integrate measurement activities into a curriculum and an academic program that has not historically emphasized measurement. One effort is to utilize a first-semester "gateway" class to introduce measurement concepts as a way to foster further measurement emphasis throughout the curriculum. The organization is using modernized teaching methods that are "research-proven, state-of-the-art teaching methods that are different, fun, challenging and more effective." This gateway class attempts to integrate nearly all facets of the measurement lab into the learn-by-doing activities to provide a fun, unparalleled experience for the first-time students. Activities in the class include micrometer calibration using gauge blocks, a study of springs using a height gauge and mass standards, pressure and force measurements of footballs, load-displacement characteristics of various bandages, and calculation of volume and surface area of various objects using calipers, micrometers, and rulers. In all cases, students are required to summarize data by developing graphs and tables using spreadsheet software. This proposal includes a "BYOE" element and involves demonstrating the use of Vernier calipers with several 3D printed artifacts to enhance the presentation.

Introduction

An environmentally-controlled metrology laboratory that resulted from a partnership between Purdue Polytechnic Columbus and Cummins Inc, a diesel-engine manufacturer, is used throughout the class as well as throughout the curriculum to reinforce the necessity of controlling the environment to obtain useful measurement information. Temperature is the largest contributor to errors in dimensional metrology and a lab controlled at 20°C ± 0.5°C with humidity below 50% is the most effective way to eliminate these errors. The collaborative partnership that created the lab evolved from a six-sigma study conducted by the industry partner, focusing on metrology skills [1] and is discussed in more detail in the work by Stahley, et al. Other courses have been developed by the author and more information on those courses can be found from an additional paper [2].

Measurement in Undergraduate Education

Measurement in undergraduate engineering education is not a frequent topic at most engineering education institutions. Significant time during that education is spent solving advanced math problems and performing computer simulations which mostly ignore the realities of the manufacturing enterprise. While those topics, particularly computer simulation, have value in manufacturing, measurement, tolerances, and geometric dimensioning are more relevant to prospective employees in manufacturing, where business and profits depend greatly on efficient and smart production. To this end, Cummins Inc, a diesel engine manufacturer, assisted Purdue Polytechnic Columbus in implementing measurement instruction in its engineering technology programs by creating an environmentally-controlled measurement center, supplying it with measurement tools and artifacts, and developing curriculum and training programs designed to meet the needs of the organization. As a result, Purdue Polytechnic Columbus has created new classes at the freshman, sophomore, and junior/senior levels, new outreach activities for K-12 students to experience the importance of measurement, and professional development activities for the current workforce.

An additional initiative has been to incorporate more measurement activities throughout the engineering technology programs. All program classes were evaluated for adding more measurement activities and these were added where most appropriate. An example included the strength of materials class where measurements of tensile test specimens and torsion test specimens were enhanced by utilizing multiple measurement tools to compare and contrast them as well as requiring an error analysis similar to that described by Taylor[3] to determine possible errors in Young’s modulus, yield strength, or ultimate strength. Similar examples have been added to manufacturing, materials, fluid power and thermodynamics classes. This work describes an effort to add measurement activities to a first semester freshman class that serves as a “gateway” class with the broader objective to provide engineering technology students a sampling of interesting and relevant hands-on activities that they can expect to experience throughout their plan of study.

Gateway Class

When students transfer into mechanical engineering technology from a mechanical engineering program, they often relate that they spent 2, 3, or 4 semesters without ever touching a piece of real equipment. They come to the mechanical engineering technology program having little idea what an engineer does and what is enjoyable about the profession. This emphasis on advanced math skills and the lack of hands-on activities may not be the case at all engineering programs. Most engineering programs are recognizing that they need to incorporate more hands-on activities into the major, especially early in the program, to improve retention and are doing so. Ultimately, such high-level mathematics and engineering theory may be necessary for only a very small percentage of engineering graduates. Much larger percentages of graduates are employed at manufacturing companies where knowledge of computer-aided design (CAD), programmable logic controllers (PLCs), rapid prototyping like 3D printing, measurement, statistics, and quality principles are far more relevant. The gateway class is a first-semester freshman class that employs many of these hands-on activities to allow students to experience what engineers do and to showcase the “learn-by-doing” approach utilized in mechanical engineering technology classes and degree programs. Cioc et al [4] and Miller [5] both implemented hands-on laboratory activities that included data acquisition and data analysis using Excel, which is an objective of the gateway class described herein. Cioc also discussed the value of these activities on retention of students after the first semester and a survey demonstrated that the students preferred hands-on activities for learning rather than just examples from a book. Interestingly, one of Cioc’s additions to their course was to add programming with an Arduino. Last fall, the students in the course at Purdue Polytechnic Columbus were asked to purchase an inexpensive kit that included an Arduino copy – Elegoo – and many new hands-on activities utilizing basic electrical concepts were added.

Measurement Activities

The institution, with the available measurement equipment, is in a unique position to add significant, relevant measurement activities to the curriculum as well as offer non-credit training programs supported by that equipment.

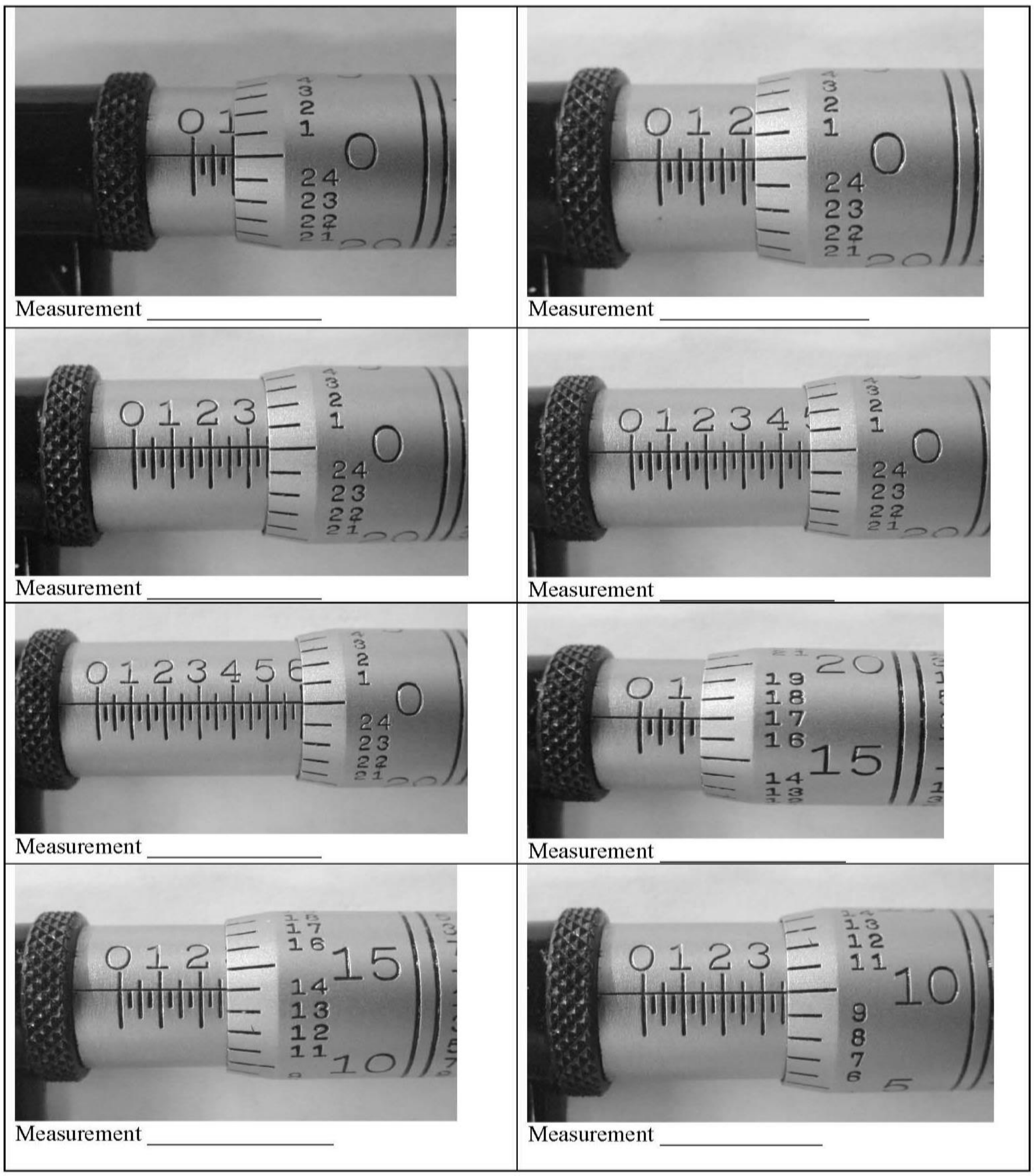

Figure 1 Worksheet providing practice reading micrometers.

Three-Point Bore Micrometers

The participants will be given worksheets similar to Figure 1 to provide some practice in reading micrometers but the majority of practice includes measuring real artifacts and recording the measurements. Figures 2 and 3 show some of the hand tools utilized with both English and metric units. PVC pipes, valves, and fittings are used to provide practice for the participants. The only way to get comfortable with reading micrometers is to do it often. The artifact shown in Figure 4 is employed in the assessment. Reading three-point bore micrometers is very similar to reading outside or inside micrometers so exercises in all three of these instruments are used in practice assignments.

Figure 2. Three-point micrometers with millimeter units.

Two-Point vs Three-Point Diameter Measurements

The differences in diameter measurements between two-point caliper measurements and three-point micrometer measurements are significant, as learned while preparing this manuscript. The three-point micrometer allows for consistent contact between the instrument and the workpiece while the two-point caliper instruments suffer from a plethora of maladies including inconsistent contact even with a single operator, alignment with the hole axis, inability to account for out-of-roundness, and others. A short exercise which exposes the flaws with two-point measurements as compared to three-point measurements is also included. Figure 3 exhibits the Vernier calipers used for making measurements of the artifact. Figure 4 is a photo of the 3-D printed part employed in this part of the training class. The hole diameters are measured with the Vernier calipers while students utilize the three-point micrometers on just a couple holes due to the limited number of these instruments. The side-by-side comparison of measurement results from these tools provides the participant an opportunity to consider measurement science in a different way – it's not just about making measurements with any tool available but promotes the idea that there might be a better or more appropriate tool for the task. This type of consideration represents critical thinking and gives the employee an occasion to improve the process and hopefully leads to the company manufacturing higher quality parts. Table 1 displays results of comparing the three-point micrometers from Figure 2 to the Vernier calipers shown in Figure 3. Referencing Figure 5, the shrinkage inherent in 3-D printing is observed as all the diameter measurements regardless of instrument are below those in the original drawing. The three-point micrometers are equipped with a ratchet stop which creates nearly uniform contact between the instrument and the part for each hole measurement. This is not the case with any set of calipers,

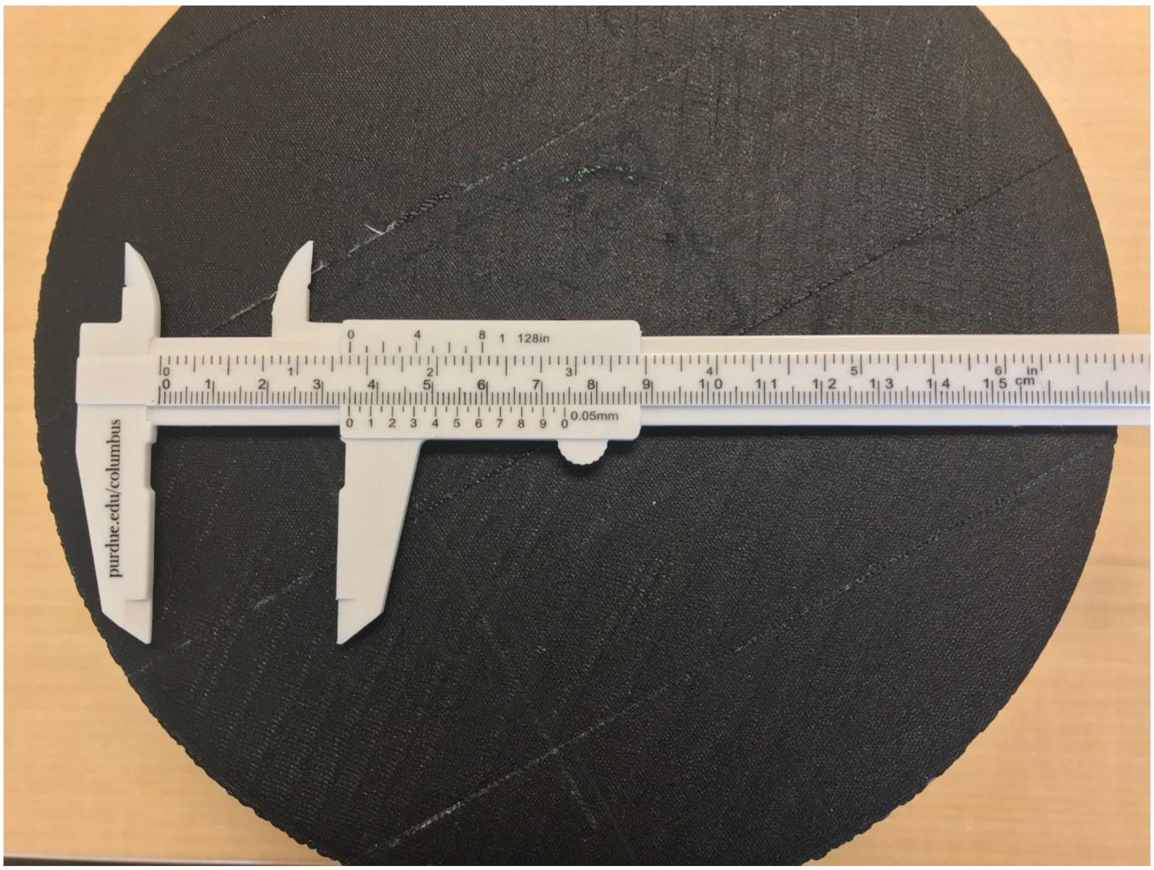

Figure 3. Verner Calipers utilized in the measurement activities.

whether digital or Vernier. The extent of the contact is very operator-dependent and likely changes from hole to hole for a single operator, despite an effort to avoid this. This is an outstanding lesson for students/participants as they begin to understand measurement with these tools. Some tools are very much dependent on the operator and their particular "feel" for the tool while others are much more user friendly.

Figure 5 shows a drawing of the plate with the 19 holes and Figure 6 is a spreadsheet submitted by a student for the exercise. The measurements recorded in the spreadsheet may not exactly match those in the drawing due to the shrinking of the plastic that occurs after the part is 3D printed. A particular format for the spreadsheet was not required so that many student

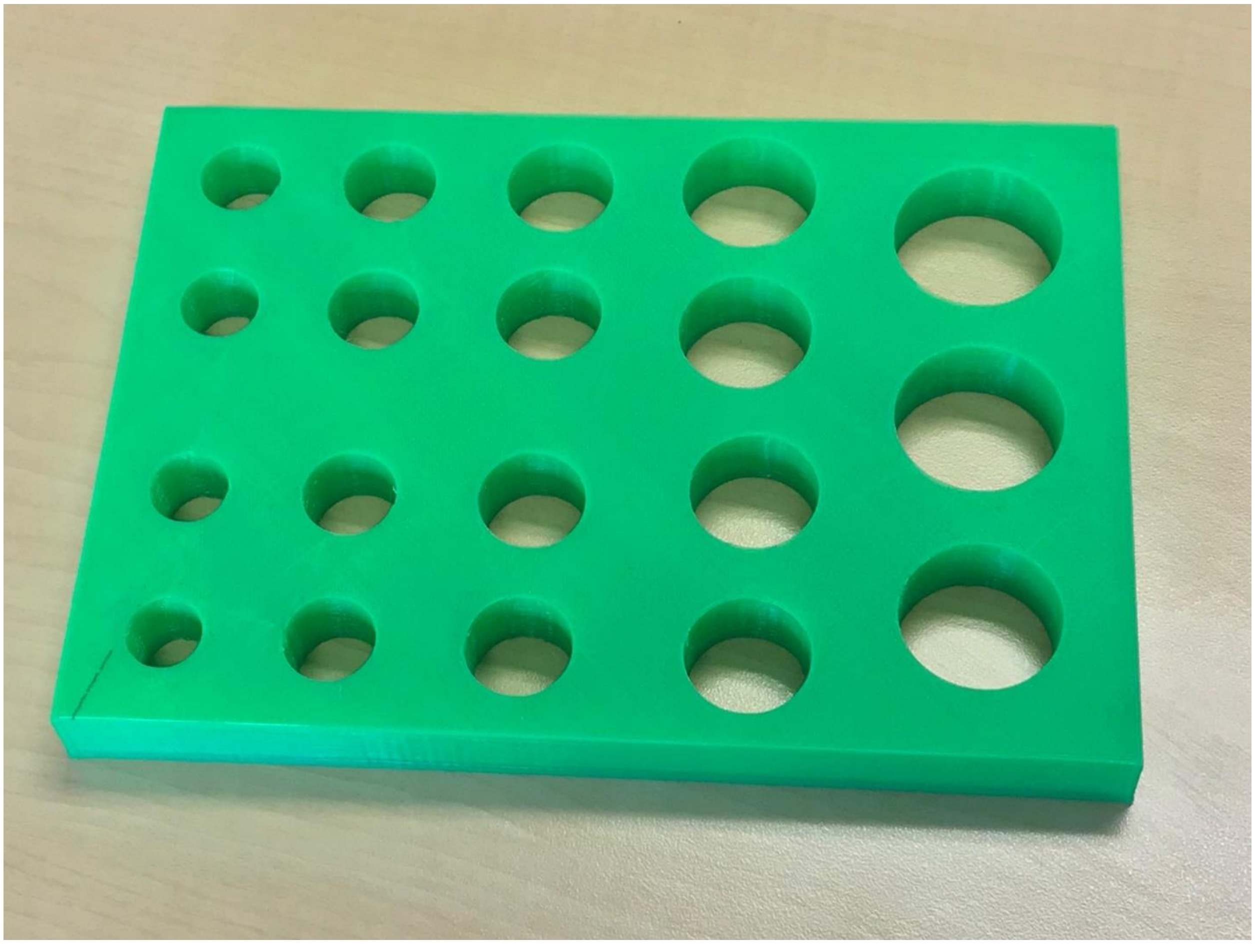

Figure 4. The 3-D printed part used to compare two-point vs three-point diameter measurements.

submissions were different, as expected. Students took different paths to computing the volume and the surface area. The Vernier calipers have a resolution of 0.05 millimeters. This particular student has consistently used two decimal places in displaying results of all calculations. It was recommended to students to go at least one decimal place more than required and then round off to the intended decimal place. Significant figures and rounding are also covered in this course as well. This habit of utilizing just 2 decimal places was not true for all student submissions. Many still displayed 6 or 7 decimal places without any round-off, indicating a teachable moment to connect a class topic to a real activity.

Hole Measurement in English Units (inches)						
Nominal Hole Diameter (inches)	Three-Point Micrometer			Vernier Caliper		
0.62	Minimum Mic Value =	0.6000	inch			
	Sleeve/Barrel Reading =	0.0000	inch	Zero-Line Reading =	0.56250	inch
	Thimble Scale Reading =	0.0142	inch	Vernier Scale Reading =	0.03125	inch
	Total Measurement =	0.6142	inch	Total Measurement =	0.59375	inch
0.65	Minimum Mic Value =	0.6000	inch			
	Sleeve/Barrel Reading =	0.0250	inch	Zero-Line Reading =	0.5625	inch
	Thimble Scale Reading =	0.0172	inch	Vernier Scale Reading =	0.0625	inch
	Total Measurement =	0.6422	inch	Total Measurement =	0.6250	inch
0.67	Minimum Mic Value =	0.6000	inch			
	Sleeve/Barrel Reading =	0.0500	inch	Zero-Line Reading =	0.625000	inch
	Thimble Scale Reading =	0.0090	inch	Vernier Scale Reading =	0.015625	inch
	Total Measurement =	0.6590	inch	Total Measurement =	0.640625	inch
0.69	Minimum Mic Value =	0.6000	inch			
	Sleeve/Barrel Reading =	0.0750	inch	Zero-Line Reading =	0.6250000	inch
	Thimble Scale Reading =	0.0044	inch	Vernier Scale Reading =	0.0390625	inch
	Total Measurement =	0.6794	inch	Total Measurement =	0.6640625	inch
0.73	Minimum Mic Value =	0.7000	inch			
	Sleeve/Barrel Reading =	0.0000	inch	Zero-Line Reading =	0.68750	inch
	Thimble Scale Reading =	0.0172	inch	Vernier Scale Reading =	0.00000	inch
	Total Measurement =	0.7172	inch	Total Measurement =	0.68750	inch
0.75	Minimum Mic Value =	0.7000	inch			
	Sleeve/Barrel Reading =	0.0250	inch	Zero-Line Reading =	0.6875000	inch
	Thimble Scale Reading =	0.0164	inch	Vernier Scale Reading =	0.0234375	inch
	Total Measurement =	0.7414	inch	Total Measurement =	0.7109375	inch
0.77	Minimum Mic Value =	0.7000	inch			
	Sleeve/Barrel Reading =	0.0500	inch	Zero-Line Reading =	0.6875000	inch
	Thimble Scale Reading =	0.0094	inch	Vernier Scale Reading =	0.0546875	inch
	Total Measurement =	0.7594	inch	Total Measurement =	0.7421875	inch
0.79	Minimum Mic Value =	0.7000	inch			
	Sleeve/Barrel Reading =	0.0750	inch	Zero-Line Reading =	0.7500000	inch
	Thimble Scale Reading =	0.0164	inch	Vernier Scale Reading =	0.0000000	inch
	Total Measurement =	0.7914	inch	Total Measurement =	0.7500000	inch

Table 1. Table of results comparing a three-point micrometer to a Vernier caliper for measuring hole diameters.

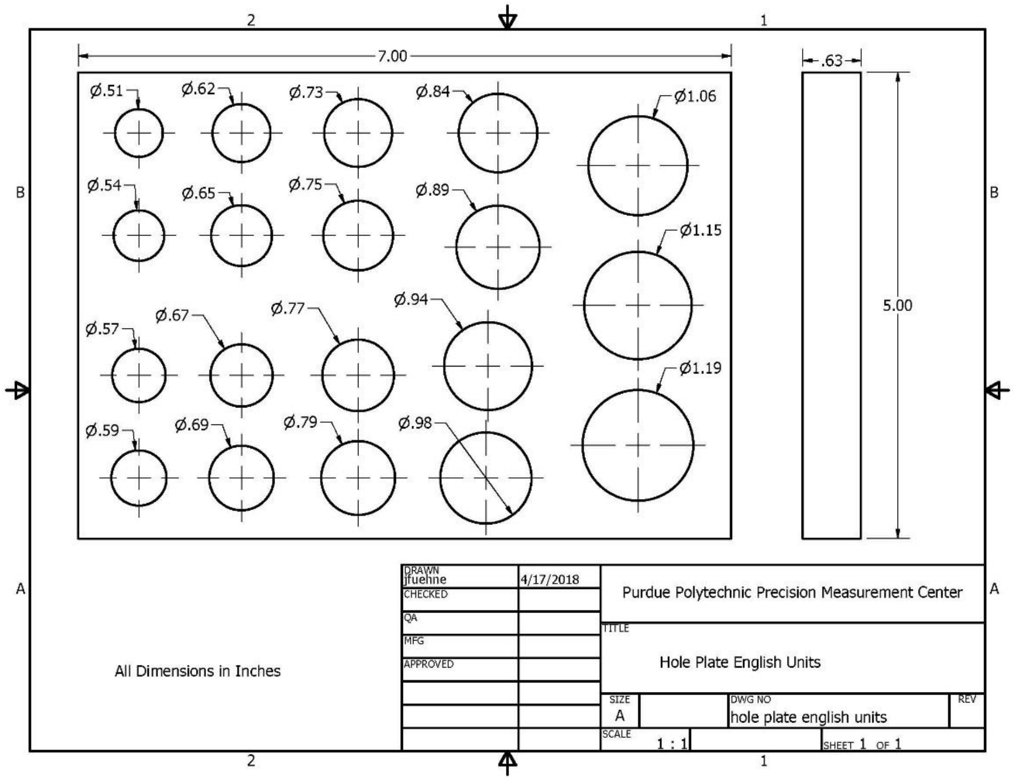

Figure 5. A drawing of one of the measureable artifacts used to practice two-point Vernier calipers and three-point bore micrometers.

Length mm	200.00
Width mm	129.00
Thickness mm	16.50

	Diameter mm	Radius mm	Hole Volume mm^3	Hole Side SA mm^2	Hole Face Area mm^2
1	19.60	9.80	4978.36	1015.99	301.72
2	18.55	9.28	4459.25	961.56	270.26
3	12.50	6.25	2024.85	647.95	122.72
4	12.00	6.00	1866.11	622.04	113.10
5	16.70	8.35	3614.15	865.67	219.04
6	16.00	8.00	3317.52	829.38	201.06
7	15.50	7.75	3113.42	803.46	188.69
8	14.90	7.45	2877.04	772.36	174.37
9	19.40	9.70	4877.28	1005.62	295.59
10	18.70	9.35	4531.66	969.34	274.65
11	18.80	9.40	4580.25	974.52	277.59
12	17.70	8.85	4059.95	917.50	246.06
13	23.40	11.70	7095.87	1212.97	430.05
14	23.00	11.50	6855.35	1192.23	415.48
15	21.90	10.95	6215.30	1135.21	376.68
16	20.60	10.30	5499.31	1067.83	333.29
17	29.50	14.75	11277.63	1529.17	683.49
18	28.60	14.30	10600.00	1482.52	642.42
19	26.40	13.20	9031.95	1368.48	547.39
			Total Hole Volume	Total Hole SA	Total Hole Face Area
			100875.25	19373.81	12227.30

Solid Volume mm^3	425700.00	Total Volume mm^3	324824.75
Solid SA mm^2	62457.00	Total SA mm^2	69603.51

Figure 6. Spreadsheet example of student work measuring the plate with the 19 holes, eventually calculating surface area and volume.

Diameter and Depth Measurements

The part shown in Figure 7 is utilized in several different ways in the Gateway class. The outer diameters are measured using a Vernier caliper. Each vertical layer is measured using a Vernier caliper and/or a depth micrometer while the holes in the center are measured using a Vernier

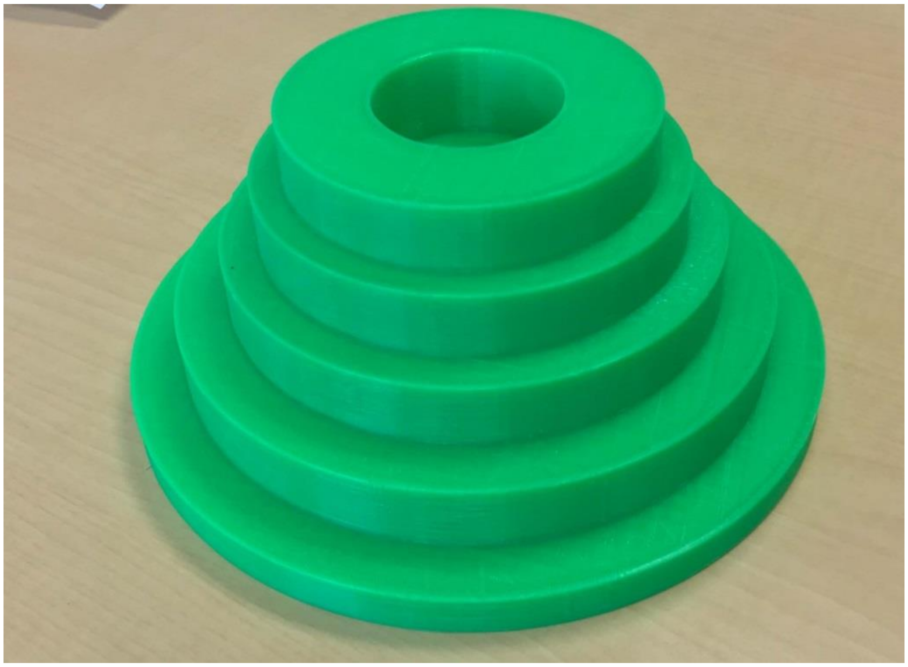

Figure 7. The 3-D printed part measured entirely with a Vernier Caliper and utilized to compute surface area and volume.

Figure 8. A Telescopic T-bore gauge set.

Caliper and/or an outside micrometer with telescopic T-bore gauges, shown in Figure 8.

The drawing displayed in Figure 9 indicates the dimensions of the artifact including internal and external diameters and depths of the various cylinders. Figure 10 provides a sample of the worksheet completed and submitted by each student for computing the volume and surface area of the object. Again, this student was consistent with using 2 decimal places in all calculations with the calipers having a resolution of 0.05 mm. This spreadsheet is designed rather well but not all student submissions were as good. Still, it's a good exercise for students to perform

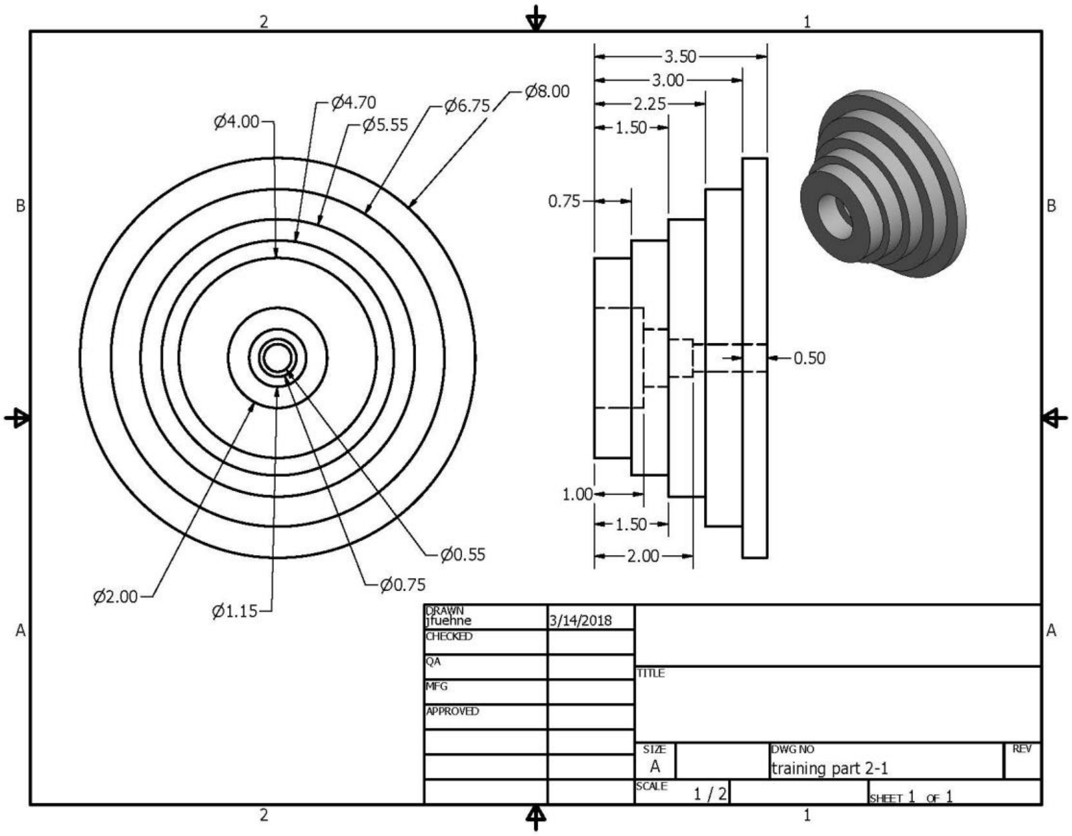

Figure 9. Drawing of the artifact used for outside diameter and depth measurements.

measurements that lead to results they have to calculate. In this way, the exercise is not just measuring something but leading to a physical property that has meaning and provides an opportunity to improve spreadsheet skills.

Simpler Shapes Results

A final exercise used in this first-semester class involved calculating the volume and surface area of three different objects using three different tools – a ruler, a digital caliper, and a micrometer. The three objects are shown in Figure 11 – a 3D printed square with a hole in the middle, a simple wooden cylinder, and a machined, aluminum artifact that basically has 2 cylinders. Figures 12 and 13 display the measurement and calculation results from 2 different students in the class. It's interesting to compare the results from the 2 students.

ENGT 181 — Volume and Surface Area Measurements

Outer	Length mm	Diameter mm	Radius mm	Cylinder Volume mm^3	Face Area mm^2	Side SA mm^2
1	19.40	102.45	51.23	159924.70	8243.54	6244.01
2	19.70	120.00	60.00	222801.75	11309.73	7426.73
3	19.00	141.00	70.50	296675.52	15614.50	8416.33
4	19.10	172.00	86.00	443792.69	23235.22	10320.76
5	13.10	202.60	101.30	422318.45	32238.05	8337.98
				Total Cylinder Volume		
				1545513.11		

Hole				Hole Volume mm^3	Hole Face Area	
A	25.55	49.90	24.95	49966.84	1955.65	4005.36
B	17.15	29.00	14.50	11327.92	660.52	1562.47
C	10.50	19.80	9.90	3233.03	307.91	653.14
D	38.80	12.00	6.00	4388.18	113.10	1462.73
				Total Hole Volume		
				68915.96		

Horizontal SA mm^2	64249.91	**Total Volume mm^3**	**1476597.15**
Vertical SA mm^2	48429.49	**Total SA mm^2**	**112679.39**

Figure 10. A submitted student spreadsheet showing calculations for surface area and volume of the stair-stepped cylinder.

Figure 11 Three simpler objects used for students to measure and compute volume and surface area.

Student 1 (Figure 12) clearly didn't have any appreciation for the differences between the tools. The measurement values for the various dimensions were all to the same number of decimal places – one. The diameter of the smaller cylinder on the aluminum part (part #2 in the tables) was recorded as 1.2 inches for all 3 tools. It's possible the student was standardizing on one decimal place for the entire table but this would have made using the various tools unnecessary and not worth the added work. Similarly, the length of the larger cylinder on the aluminum part was listed as 1.2 inches using the ruler and caliper but 1.5 inches using the micrometer. Clearly, the instructor didn't emphasize enough that these values should be very similar from each of the tools. This likely shows apathy on the part of the student and the instructor in the future will hand the spreadsheet back to the student for re-measuring, noting that the difference in values is incorrect unless the micrometer has not been recently calibrated (they were calibrated in an earlier lab exercise in the same class).

Student 2 (Figure 13) tended to measure at the other end of the spectrum. Of particular interest are measurements on the alumuinum cylinder made with the ruler that go to 4 decimal points, which works in this case since the ruler has a 1/16th of an inch resolution. The same ruler, however, has a 1mm resolution for the metric side. The metric mesaurements for the square block and the cylindrical block are more realistic in this case, although the micrometers used in the exercise have resolution down to the third decimal place. On the other hand, student 2 clearly decided to keep nearly every number/decimal place available from the spreadsheet program, indicating yet another student who failed to learn much during the significant figures discussion earlier in the semester.

Measurements Lab ENGT 180

Square Blocks with Hole - Number 63						
Instrument	Circle Diameter (mm)	Length (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Surface Area (mm^2)
Ruler	37.0	74.0	74.0	15.0	66011.8	13241.6
Caliper	36.4	74.5	74.5	14.9	67193.5	13459.5
Micrometer	36.5	74.1	74.1	14.5	64485.2	13197.5

Aluminum Cylinder - Number 2						
Instrument	Small OD (in)	Large OD (in)	Sm OD Length (in)	Lg OD Length (in)	Volume (in^3)	Surface Area ^3
Ruler	1.2	2.3	3.9	1.2	9.1	32.4
Caliper	1.2	2.2	4.0	1.2	8.9	32.1
Micrometer	1.2	2.2	3.9	1.5	10.4	34.8

Cylindrical Block - Number 11				
Instrument	Length (mm)	Diameter (mm)	Volume (mm^3)	Surface Area (mm^2)
Ruler	25.0	28.0	13744.5	3430.6
Caliper	24.6	28.2	13403.2	3464.0
Micrometer	24.4	27.2	12737.3	3305.0

Figure 12. Spreadsheet from Student 1.

Again, this represents a “learning moment” when the student is reminded of significant figures and how many of the digits in the volume and surface area calculations are not important.

Another aspect of this exercise is in the units with two of the objects requiring the measurements and calculations be done in millimeters while the third is done in inches. This gateway class is a first semester class that has a significant unit conversion module so the differences in units in this exercise offer a good comparison in reading measurement tools for different unit systems.

Calculation Activities

After taking the measurements, students are then asked to develop an Excel spreadsheet that records the measurements and also calculates the volume and surface area of the objects. The Gateway class also has a module and related exercises to teach students spreadsheet analysis with plenty of opportunities to practice. This exercise was one of those opportunities.

Square Block						
Instrument	Diameter (mm)	Length (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Surface Area (mm^2)
Ruler	26	50	50	14.7	28945.34137	8078.858395
Caliper	24.7	49.5	49.5	14.7	28974.97059	7993.453746
Mic	24.4	49.4	49.4	14.788	29173.25399	8001.21158

Aluminum Cylinder						
Instrument	Small OD (in)	Large OD (in)	Sm OD Length (in)	Lg OD Length (in)	Volume (in^3)	Surface Area (in^3)
Ruler	1.25	2.3125	3.9375	1.125	9.557083804	97.42005188
Caliper	1.16	2.26	3.97	1.17	8.889076723	97.25365546
Mic	1.19	2.263	3.965	1.185	9.176137996	98.68945598

Cylindrical Block				
Instrument	Length (mm)	Diameter (mm)	Volume (mm^3)	Surface Area (mm^2)
Ruler	25	29	16512.99639	3598.694385
Caliper	24.5	28.2	15302.21087	3419.686435
Micrometer	24.2	27.8	14689.08822	3327.512107

Figure 13. Spreadsheet from Student 2.

In addtion, the procedure for computing the propagation of error that’s described by Taylor(3), will be employed for the volume and surface area calculations to give students a sense of how simple measurement errors can make their way into important calculations and, therefore, important decisions. An important first step in this procedure is for students to estimate the error in their measurements and acknowledging that the error is different for different instruments. Is the measurement error simply the resolution of the device? Or, is it possible to estimate a value smaller than the resolution? And is that estimation ability different for each device? Certainly a ruler graduated in 1/4 inches is different in this respect than one graduated in 1/16 of an inch. But, realistically, how much better is it?

Conclusions

The role of instructor in the current learning environment has changed from one of basically informing students to one of asking questions of students to initiate their own learning. The use of measurement tools in a manufacturing environment is critical and students headed for careers in that environment need to understand this critical role. And understanding comes from not only learning how to use the tools but also developing knowledge through the aforementioned coaching by instructors to learn which tool is best for each application. Certainly, questions surrounding the ability and/or necessary training of production workers, the desired efficiency of the measurement operation to support production, and the accuracy, precision, and uncertainty required of the measurement, drive the selection of measurement tools. And it is critical that manufacturing engineers supervising and managing production lines need to be aware of the details and features of various measurement tools. This work aims to get beginning students in their first semester of college classes an introduction to many of these measurement tools as well as to the critical thinking required to utilize these tools in a manufacturing environment. These topics and skills are likely covered in engineering technology programs but not in traditional engineering programs.

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