Teacher Name(s), School and District: Malcolm Paradise, Lynn School District

Course Name: Introduction to Engineering Design

Lesson/Unit Name: L3 - Measurement and Statistics

Science or Education Topic(s): Measurements systems and the use of Statistical Process Techniques in Manufacturing

Engineering Technology Industry Related Field/Activity: QC/QA; Manufacturing, Metal working

When Taught: End of freshman Year or early on in sophomore year

Abstract: In 200 words or less, please provide a summary of your objectives, implementation, and the results of your implementation.

Students come to our shop without any knowledge of variation in products. All of a sudden we get into measuring things and they get told there's no such thing as a 3/4" cube. We can't make one EXACTLY 1". There's variation in every manufacturing operation. And we learn that when we start measuring 3/4" cubes and we realize that none of them are exactly .75" across any of their 3 faces. So in every class they've taken nothing prepared them for reality. Their nice defined world is thrown into chaos. Later in the course they will discover this when they fabricate their puzzle cubes. If they don't pay attention to stacking issues or aligning faces their cubes aren't easy to assemble as they should be. This intent here is to create an understanding of how stacking of tolerances (the allowable variation in a part's measurement) and assembly operations/techniques affect overall fit and finish.

Objectives and assessment: Using the table below, identify at least 3-5 learning objectives (content and/or pedagogical) and describe how each will be assessed.

Objectives *By the end of this lesson/unit, the students will be able to:*	**Assessment** *How was the objective assessed? List the example of formative or summative assessment.*
Calculate mean and standard deviations	Results presented upon completion of each activity
Understand that how you assemble things affects final results.	Results again from building various stacks of cubes.

How to affectively use a dial caliper	The readings/measurements made all make sense?

Engineering/Technology Link: Please check the appropriate box(es) in question 1. And provide a brief answer to question 2.

1. How did you *introduce* engineering/ technology concepts or the company/industry focus in your course? Check the appropriate box(es) or choose Other.

   - ☐ X Defined terms (science, engineering, technology)
   - ☐ Described the engineering design process
   - ☐ Engineering design challenge related to industry
   - ☐ X Overview of the company
   - ☐ X Challenge based on 'industry specific' area of focus (manufacturing process, quality control, measurement, development, teamwork etc.)
   - ☐ Other: _____

2. After introducing the concepts, what did/will the students do to explore and apply the engineering/technology and industry specific concepts? (include information about the actual activity students did, discussions they had, or instructional strategies you used)

Students will be given 24 – 3/4" cubes to measure per instructions. Data will be collected and analyzed to determine the Mean and Standard deviation of the thickness measurements taken across each of the 3 face sets on any given cube. Students will then be instructed to create 2 sets of stacks - 6 cubes each, with no other instructions. Stacks will be assembled using Tightbond glue. Students will then be asked to create two additional stacks of 6 each but this time making sure they are assembled with the grain aligned on all 6 cubes. Once these cubes dry, measurements for each will be made. 3 measurements per stack will be made using their dial calipers. Students will then gather as a group and combining results calculate the Mean and Standard deviation for each of the assembled groups: random and aligned stacks. Histograms for each group separately and combined will be created.

Students will then use these hard results and visual aids to compete some inquiry questions to analyze their findings in detail. Finally, a 'what have you learned' question will be presented for students to reflect on the results of this investigation.

Level of Inquiry: Which of the following best describes the level of inquiry (adapted from Bell 2005) you used for this lesson/unit? Check the appropriate level.

- ☐ *X Structured inquiry*: Instructor provides question and procedure. Students determine the results based on given procedures.
- ☐ *Guided inquiry*: Instructor provides question. Students design procedure and determine the results.
- ☐ *Open inquiry*: Students investigate their own research question. Students design procedures and implement the procedure on their own.

Lesson Extension Plan:

Title/Topic: Investigation of How Measurements Stack; or What are tolerances?
Time (minutes): 120 minutes
Company Name and brief Description: BOMCO, Gloucester, MA a maker of thin metal components for the aircraft industry. BOMCO Uses Leading Edge Technologies and Manufacturing Techniques to Economically Produce Precision Formed Metal Components for Jet Engines, Industrial Gas Turbines and Land and Marine Turbines. See www.bomco.com for more details. Essentially they manipulate sheet metal stock into components that go in turbine engines. Since almost all the parts they make are circular in nature and usually have no easily identified origin, parts are analyzed using polar coordinates with an origin at the center of the object/part. Tolerances or variation in part dimensions accumulate as assembles are made and very inventive, unique and precise measurements need to be made if final assemblies are expected to work and function as the designer intended. Skills needed to work at BOMCO could include the knowledge of processes including: Spinning, EDM (Electro-Static Discharge Machining = using a metal electrode to burn away metal), Drawing, Milling, Turning, multi-axis laser machining, CNC machining, CNC plasma cutting, CNC expanding, CNC spinning and hydraulic forming, etc..
Overview of the Lesson In this lesson how measurements are affected when stacked will be explored. This stacking effect forces us to create tolerances that allow assembled parts to function as desired. This concept is the foundation for what is referred to as the industrial advancement first utilized in the mid-19th century as interchangeable parts. Without a thorough understanding of this the world as we know it would not exist. One could not order a spare or replacement part for anything and expect it to work just like the part being replaced. We take this concept for granted today but 100 years ago FORD Motors was still using machinists to assemble cars as

parts needed to be modified to make them work in their cars. Vendors were still being trained on how to hold tolerance, as this is referred to, so the parts they produced could be interchanged or used as they came out of their shipping containers and built into cars. The ultimate result of this effort is that skilled labor needed to build cars was replaced with less skilled labor reducing car cost so the average person could afford to buy a car. Back then a FORD might have sold new for a few hundred dollars whereas a hand assembled car might be thousands more. Think Lamborghini versus a Ford today.

Standard(s)/Unit Goal(s) to be addressed in this lesson:
2.B.10.04, 2.D.01.05, 2.D.01.06, 2.D.02.04

Essential Question(s) addressed in this lesson:

- **EQ1** – Can statistics be interpreted to justify conflicting viewpoints? Can this affect how we use statistics to inform, justify and validate a problem solution?
- **EQ2** -- Why is error unavoidable when making a measurement?
- **EQ3** – When recording measurement data, why is the use of significant figures important?
- **EQ4** – What strategy would you use to teach another student how to use units and quantitative reasoning to solve a problem involving quantities? (For example, a problem like A3.2 number 4 or number 5.)
- **EQ5** – What would happen if engineers did not follow accepted dimensioning standards and guidelines but, instead, used their own individual dimensioning methods?
- **EQ6** – When measuring the length of a part, would an inaccurate (but precise) measuring instrument be more or less likely to indicate the actual measurement than an imprecise (but accurate) measuring instrument? Justify your answer.

Objectives
Create awareness of why we use tolerances and that nothing is exactly what you expect it to be

Link to Industry:

What students should know and be able to do before starting this lesson

- They should know how to use basic measuring tools such as a dial caliper.
- They should have a basic understanding of mean and std dev. And how to plot data into a histogram using Excel.

Instructional Materials/Resources/Tools
3/4" wooden cubes, Dial Calipers, pens/pencils/sharpies, paper or engineering notebook, computer with Excel

Lesson Delivery

Lesson Opening
Students will be reminded of what they learned in L3 already and that they will need to use this knowledge to complete today's activity. Instructions on part one will be presented as 24 cubes ad a caliper will be given to each student. Students will be told to collect data in their Engineering Notebooks and online using Excel to crunch data.

Once individual cubes have been made, students will be told how to assemble their cubes into stacks. Hopefully there will be an even number of students for each of the 3 assemble techniques. Height of stacks will be made and the group will combine results for analysis using Excel and statistical methods and share the results with each group member.
During the Lesson (activities/labs/challenges) Teacher will roam the room making sure students are able to use the caliper and make good measurements on each and every cube in their group.
Lesson Closing Discuss results and what the group found after crunching their data and reflecting on the results.
Assessment
Student Assessment: Results from their measurements and the answers to the various questions to be answered at the end of their efforts.
Delivery Assessment: Self-reflect on the students' results to see if the intended result was realized. If the result isn't achieved discuss with students why it wasn't and what could be done to achieve the expected result.

Additional resources and assessments: List the attachments here.
Attachments should include handouts, readings (with references), lab write-ups, rubrics, exams/quizzes, and/or other similar materials.

Title: Catapult Exercise for LSDPS	Version: 2	Owner: Process Solutions	Date: 5/8/2013

DEFINE: Background

Background:
Customer has requested that we develop and deliver a catapult that is preconfigured to hit 2 targets (20 in and 35 in).

Problem Statement:
The catapult is unable to hit the target and we are unable to meet customer demand.

Goal:
Improve the number of balls that hit the target from 0% to 100% by 3:50 pm today.

Do no harm: Leadtime to hit the targets must be less than 18 seconds.

ANALYZE: Find Root Cause

Key Inputs:
- X1 - Catapult settings
- X2 - Rubber Band
- X3 - Pullback Angle
- X4 - Launch Sequence
- X5 - Work Method / operators
- X6 - Stability of Catapult

Adjustment	Trial 1 Holes	Trial 1 No Holes	Trial 2 Holes	Trial 2 No Holes	Trial 3 Holes	Trial 3 No Holes
X2 - Rubberband Size	Large	Large	X-Large	X-Large		
X3 - Pullback Angle	90°	170°	105°	170°	105°	170°
X1 - Hinge Point	3	3	3	3		
X1 - Stop Position	4	4	4	4		

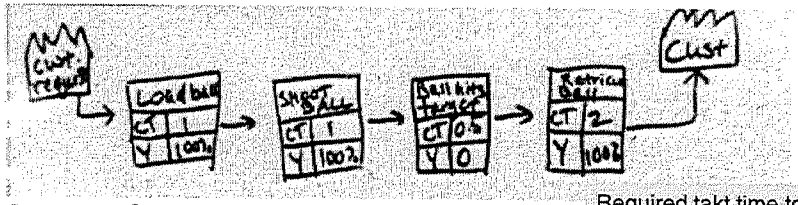
Green = hit, Red = miss

Trial with new settings:

	No Holes	Holes	Comments
X4 - Balls in "Batch"	5/5	5/6	Unable to get yield and meet takt
X4 - Alternate Balls	6/6	5/6	Unable to get yield and meet takt
X5- Alternate Balls and adjusted work method	5/5	5/6	Able to get needed hits and meet takt

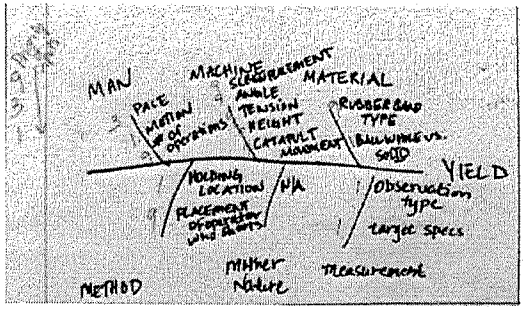
MEASURE: Current Situation

Process Thinking:



Current Performance:
LT = 4.5 sec / ball
Time to shoot 10 balls = 45 sec
Yield = 0%

Required takt time to shoot 1 ball needs to be 18 sec / 10 balls = 1.8 sec/ball



Likely Suspects (may include):
- Pullback angle
- Launch sequence
- Work Method
- Catapult settings
- Stability of catapult
- Rubber Band type

Make sure that items in orange are identified and carried over to analyze

IMPROVE: Optimize &Take Action

X	Countermeasure	Experiment	Result
X6	Tape down catapult		Increase accuracy
X4	Alternate launch sequence	Alternate ball launch (holes, no holes, holes)	Improve Speed
X5	Additional operator at launch	Additional operator puts ball in cup for the launcher	Improve Speed
X5	Audible cue from launcher	Launcher signals the release	Increase accuracy
X5	Audible cue for "hit"	Cut tin foil down to target size - improve ability to tell normal from abnormal	Increase accuracy
X3	Hard Stop for Pullback Angle	Pullback 100% for far target. Pullback to masking tape for short target	Increase accuracy

CONTROL: Demonstrate Improvement & Sustainability

Demonstrated Improvement:
Improved Yield = 100%
Time = 17 seconds
Happy customer!

	No Holes	Holes
Run 1	5/6	5/5
Run 2	5/5	5/5
Run 3	6/6	5/5

Sustainability:
- Mark pullback angle with tape
- Audible cues
- Daily rubber band check
- Screw catapult to floor
- Document standard work with pictures

Introduction to Engineering Design: Tolerance Stack-Up Project
Student's Tolerance Stack-Up Report Rubric (Auto Scorer)

Section	Attributes/Questions	Blank = NO	Score	Totals
Cover Page	Author's Name	1	1	
	Instructor's Name	1	1	
	Date	1	1	
	Class/Subject	1	1	
	School or Institution	1	1	
	Title	1	1	
TOC	Is it present?	1	1	
	Are Page numbers on Right?	1	1	
	Is it organized - includes all sections in report?	1	1	
Hypothesis	Is a Hypothesis given the premise of the project presented?	1	1	
	Did it include a prediction on how orientation in individual cubes wil affect variation made?	1	1	
	Was an outcome for Stacks and how they might vary made?	1	1	
	Did it make sense?	1	1	
	Was it professional and on point?	1	1	
	Was it set up as a negative hypothesis such that disproving the statements makes its opposite true? For example: All cubes will measure the same in all directions. Or Orientation will not affect Stack Measurements. Made?	1	1	
	Does the Hypothesis make reference to Tolerances?	1	1	
	What a Tolerance is?	1	1	
	How a Tolerance can be used to specify workable parts?	1	1	
Process Instructions	Are instructions on how to repeat this experiment included?	1	1	
	For measuring 24 individual cubes?	1	1	
	For creating 2stacks of 6 cubes each?	1	1	
	For measuring these 2 stacks?	1	1	
	For creating 2 additional Stacks but with them oriented such that the grain is aligned with the stack?	1	1	
Results	Are instructions to collect the data from the class included?	1	1	
	Is data to be analyzed in an Excel Spreadsheet included?	1	1	
	Are instructions how to compute statistical data: XBar and Std Dev included?	1	1	
	Was it explained that computing individual cube data as a group and then seperately specified?	1	1	
	Was it explained that histograms of each data set are also to be created?	1	1	
	Are results for the stacks included?	1	1	
	How about statistics on the stacks both the first 2 and the second 2 included?	1	1	
	Are histograms for individual and then the stacks as a whole included?	1	1	
Discussion of Results	Is there a DOR section?	1	1	
	Are individual cube resutls analyzed and compared?	1	1	
	Is stack data discussed?	1	1	
	Were all 3 stack groups: undirected assembly (random orientation), Directed assembly, and the whole group, discussed?	1	1	
Conclusions	Is a conclusion included?	1	1	
	Were individual results results summarized and discussed?	1	1	
	Were inferences made about how orientation affects variation in measurements discussed?	1	1	
	Was it evident that orientation affected variation in individual parts?	1	1	
	...in stacks?	1	1	
	Was the hypothesis about indivdual cubes, made at the beginning of this effort discussed?	1	1	
	Was the hypothesis about stacks, made in the beginning of this effort dicussed?	1	1	
	Was a reflection statement made as to what was learned in this activity included?	1	1	
	Did the conclusion discuss tolerances and why they are needed/important?	1	1	
	Bonus Points		3	Teach Discretion
	Target Score:	44	47	Grand Total
			106.8%	Grade