MANUFACTURE YOUR PATH

METROLOGY: The Science of Measurement

Topic(s): Metrology, Precision, Accuracy, Tolerance

Grade level(s): 9th – 12th grades

Time: 45-60 minutes

TEKS Alignment: PRINMAN.1.C, PRINMAN.2.C, PRINMAN.2.E, PRINMAN.7.A, PRINMAN.7.B, DIMANU1.2.A, ENGDPRS.10.A, ENGDPRS.10.E

ACTIVITY OVERVIEW

In this activity, students are introduced to metrology, the science of measurement. Students work through exercises to understand the difference between precision and accuracy and how both play an important role in the manufacturing industry. Students will use tools like rulers and calipers to measure items and collect class data to calculate averages and standard deviations. Students will also be introduced to the idea of tolerance in a designed part. Students will see that different tolerances are required depending on the function of the part. Interference and clearance fits will be discussed as students try to determine the best hole tolerance for a pin.

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ALIGNMENT TO STANDARDS

Texas Essential Knowledge and Skills (TEKS):

Principles of Manufacturing

PRINMAN.1.C: Use a variety of measuring instruments
PRINMAN.2.C: Apply mathematics concepts to solve manufacturing problems
PRINMAN.2.E: Use the appropriate units of measure
PRINMAN.7.A: Investigate an area of interest in manufacturing
PRINMAN.7.B: Analyze the various specializations in manufacturing

Diversified Manufacturing I

DIMANU1.2.A: Use tools and equipment commonly employed in manufacturing in a safe manner

Engineering Design and Problem Solving

ENGDPRS.10.A: Evaluate the readings of dial calipers and micrometers to make precise measurements
ENGDPRS.10.E: Examine the maximum and minimum limits of a dimension given its tolerance

LEARNING OBJECTIVES

Students will know:

- How to measure with rulers and calipers.
- What averages and standard deviations are.
- What tolerances are.

Students will understand:

- The difference between accuracy and precision.
- The importance of precise measurements in manufacturing.
- That tolerances are determined by the function of interacting pieces.

Students will be able to:

- Measure metal pins for their length and diameter using rulers and calipers.
- Calculate class averages and standard deviations.
- Determine fits for metal pins by testing with a tolerance block.

CAREER CONNECTIONS

Metrologist

By evaluating and calibrating the technology in our everyday lives, metrologists keep our world running smoothly.

Work Environment: Workers in scientific and legal metrology are usually employed by government agencies. But most metrology workers have jobs in industrial metrology, where they test new products for private companies as well as for government.

Duties: Professionals in these jobs have the following duties and more: supervise the manufacture of products, test manufactured components, check assembly process to ensure that machinery is functioning correctly, develop tests to evaluate a structure's resistance to stress.

Source: https://www.bls.gov/careeroutlook/2009/fall/art02.pdf

Calibration Technologists and Technicians

Calibration technologists and technicians inspect, adjust, and test measurement devices against standards, such as those used in manufacturing, healthcare, and other industries.

Work Environment: Calibration technologists and technicians work in a variety of settings, depending on the industry in which the tools they calibrate are used. For example, in manufacturing they may work in a plant that produces chemicals, computers and electronics, machinery, or other products. Research and development might require working in a testing laboratory.

Duties: Professionals in these jobs have the following duties and more: inspect equipment for defects, compare readings of measurement devices with established standards to ensure proper output, adjust, if necessary, and test devices to check that calibration was successful and readings are accurate.

Median US Salary: $62,790 (US Bureau of Labor, 2023)

Source: https://www.bls.gov/ooh/installation-maintenance-and-repair/calibration-technologists-and-technicians.htm

Mechanical Engineering Technologists and Technicians

Mechanical engineering technologists and technicians help mechanical engineers design, develop, test, and manufacture machines and other devices.

Work Environment: Mechanical engineering technologists and technicians work primarily in factories or in research and development labs. Most work full time.

Duties: Professionals in these jobs have the following duties and more: evaluate specifications in design drawings prior to adding or replacing tools, plan, produce, and assemble mechanical parts for products, such as industrial equipment, set up and conduct tests of complete units and their components, and record results

Median US Salary: $64,020 (US Bureau of Labor, 2023)

Source: https://www.bls.gov/ooh/architecture-and-engineering/mechanical-engineering-technicians.htm

BACKGROUND INFORMATION

In this activity, students will see hands on the difference between precision and accuracy. They will do this using a variety of measuring tools and units of measure with 3 metal dowel pins of different lengths and diameters.

In the first half of the activity, students will use the measuring tools provided to determine the length and diameter of each given metal dowel pin. Class data will be collected so the class can discuss what an average is as well as what a standard deviation is. Students will also learn the importance of tool calibration for best accuracy as they realize that the rulers provided are not actually measuring 12 inches but rather 9 inches. Students will have the opportunity to discuss the pros and cons of using English and Metric measurements and why one can be preferred over another in certain circumstances.

In the second half of the activity, students will work see that small differences can lead to greatly different part functions. Students will use a tolerance block with slightly different sized holes to see that though they all look the same, the pins fit differently into each: some slide right through while others can be pushed in and hold firm. Students will make an informed decision about the size hole needed for a specific situation based on their observations.

Additional Resources

Measurement and Precision Lesson Plan

- http://flate.pbworks.com/w/page/27835806/CONMED-%20Measurement%20and%20Precision%20HS

Difference Between Accuracy and Precision in Production Machining

- https://waykenrm.com/blogs/difference-between-accuracy-and-precision/

Accuracy Versus Precision: The Most Important Concept in Quality and Metrology

- https://www.youtube.com/watch?v=xMvwYDQXWnE

Types of Fits: How to Choose a Fit for Engineering Application

- https://waykenrm.com/blogs/types-of-engineering-fits/#:~:text=A%20clearance%20fit%20has%20a,of%20freedom%20(of%20movement)

PRE-ACTIVITY RECOMMENDATIONS

Students should be familiar with measuring with standard 12 inch rulers (measuring in inches and centimeters) and familiar with the basics of significant figures.

Using a Ruler (https://edex.adobe.com/teaching-resources/ruler-worksheet)

POST-ACTIVITY RECOMMENDATIONS

Students can explore more precise measuring instruments like dial or vernier calipers and micrometers.

The Ruler Game (https://www.rulergame.net/)

ACTIVITY FILES

The Manufacture Your Path classroom activity set includes all of the materials needed for 16 student stations. In the case that you would like to create more of the custom items, the files described below can be downloaded from our website (learningundefeated.org/curriculum).

1. Trick Ruler (11.4 Ruler.svg)
    a. This SVG file can be cut and engraved with a laser cutter/engraver.
    b. We recommend using 1/8" plywood or acrylic for these. If using acrylic, it is recommended to paint the engraved area for legibility.
2. Tolerance Block (Tolerance Block.svg)
    a. This SVG file can be cut and engraved with a laser cutter/engraver.
    b. We recommend using ¼ inch acrylic for these. It is recommended to paint the engraved area for legibility.
3. Data Collection Spreadsheet (Metrology.xlsx)
    a. This spreadsheet is set up to collect class data and quickly calculate averages and standard deviations.
        i. Students can calculate these on their own, but we recommend using the spreadsheet when time needs to be saved for other activity components.

STUDENT STATION SET-UP

Students will work in pairs at an individual station.

1. Trick ruler
2. Digital caliper
3. Small metal dowel pin (4mm x 30mm)
4. Medium metal dowel pin (5mm x 35mm)
5. Large metal dowel pin (6mm x 30mm)
6. 1-2-3" block
7. Acrylic tolerance block

LESSON PLAN

Introduction (5-10 min)

- Welcome students to the classroom and direct them to take a seat.
- Explain to students that they will be acting as metrologists at a manufacturing company.
- Ask students if they have heard of metrology before? If not, what does it make them think of? What does ology mean? What does metr sound like?
    - Metrology is the science of measurement.
- Explain that metrology originally stemmed from the need to manufacture interchangeable parts.
- Ask students why interchangeable parts resulted in a need to measure things more precisely?
    - To make interchangeable parts possible, the dimensions of all the parts had to fall within a specific range — otherwise, they simply wouldn't fit their companions. In its modern application, metrology has become a highly advanced field with many tools and statistical methods to measure the accuracy and quality of manufactured parts.
- Explain that precision and accuracy play a huge role in metrology. Explain that we often use these terms interchangeably but they do have different definitions.
- Ask students what is the difference between precision and accuracy?
    - Explain that accuracy is a measure of how close a measurement is to the true or accepted value. Precision tells us how close a group of measurements are to each other.
- Using the example images on the first page of the student handout, walk through scenarios of different levels of precision and accuracy. The image can be interpreted as a dart board, archery bullseye, or other similar item.
    - Ask students which of the bullseye images shows dots with high accuracy?
        - Top left is the most accurate (all dots are within the bullseye), but the bottom left also shows high accuracy as all of the dots are very close to the center.
    - Ask students which of the bullseye images shows dots with the high precision?
        - Top left and top right are both highly precise as all of the dots are very close to one another. It shows that it can repeatedly shoot to a very similar location.

Part 1: Precision and Accuracy (30 min)

- Have students turn to page 2 and explain that to learn more about precision and accuracy, we will be measuring metal dowel pins.
- Direct students to at their station materials and remove the 3 metal dowel pins. Ask students what is similar about the pins and what is different?
    - All pins appear to be made of the same material (steel) and have the same shape (cylindrical with chamfered ends).
    - The pins are different widths (diameters) and some are different lengths.
- Explain that our goal is to determine the diameter and length of each pin.
- Direct students to find their ruler. Explain that the ruler has scales for measuring in inches or in centimeters.
- Ask students which scale on our rulers will allow for the most precision?
    - Do not correct students or tell them the correct answer. Allow students to explain their reasoning.

        - The correct answer is centimeters for these rulers as the smallest centimeter increment (1mm) is smaller than the smallest inch increment (1/10" ≈ 2.54 mm).
    - Have students vote for which they think is more precise via raising hands.
        - If the class is more or less split, direct groups to measure using their hypothesized more precise scale.
        - If the class has a majority in one opinion, explain that we'll divide the class to measure both and then compare. Designate half of the groups to measure in inches and the other half to measure in centimeters.
- Direct students to use the ruler to measure the three pins and record their data in Table 1 or 2 accordingly.
    - They only need to fill out the table for the scale they voted for/were assigned to.
    - If needed, remind students that the smallest mark on the inches side of the ruler is to 1/10 of an inch. When they record their measurements, they should have two decimal places. The first decimal place will be the last line that the pin passed and the second decimal place is an estimation of the pin's location between two lines.
    - If needed, remind students that the smallest mark on the centimeters side of the ruler is to 1mm. When they record their measurements, they should have two decimal places. The first decimal place will be the last line that the pin passed and the second decimal place is an estimation of the pin's location between two lines.
- Ask students if one measurement is enough to give a strong argument of the manufacturers set length/diameter?
    - More measurements (measuring the length/diameter of multiple pins in a batch or across batches) will give the strongest argument.
- Explain that we'll calculate the class averages for these measurements.
- After students have all taken their measurements for the three pins, have students share their length/diameter for each pin and record it in the provided spreadsheet. This will automatically calculate the class average and standard deviation.
    - *Teacher's Note: The spreadsheet can be projected for students to view, but it is not necessary. If not projecting, it is recommended to at least write the average and standard deviations for students on a whiteboard for students to see.*
    - *Teacher's Note: If having student calculate the average and standard deviation, the spreadsheet can still be used to show students the class data. The calculation fields can be hidden or removed.*
    - If needed, review what an average is. An average is a single value that best represents a set of data. It tells us that of all of the measurements, most of them were about this value.
    - If needed, review what a standard deviation is. Standard deviation is the amount of variation of the values relative to the average. If we took each measured value and compared it to the average, we'd take the difference. Then we'd average all of those differences to get the standard deviation.
- Have students record the averages and standard deviations for all measurements (inches and centimeters) in their tables.
- Ask students to compare the standard deviations for measurements in inches to those in centimeters. Which has the smaller standard deviation?
    - Centimeters

- Explain that the smaller increment (1mm) allowed for less variation between each measurement. Ask students if that means measuring in centimeters allowed for more precision or accuracy?
    - Precision, the values are all closer to one another, but we can't speak to their accuracy.
    - Ensure students understand that metric might not always be the most precise depending on the tool they are using. For example, a ruler with 1/32" or 1/64" will be more precise than a metric ruler with mm markings. This is because 1/32" and 1/64" are both less than 1mm. Hit home that the scale with the most increments in a certain distance is the most precise.
- Direct students to find the 1-2-3" block. Explain that this is a precision ground tool that can quickly give you an accurate measurement. This tool is a calibrated standard that is used to ensure accuracy of other tools. This tool is 1" x 2" x 3".
- Direct students to compare their 1-2-3" block to their ruler to determine the ruler's accuracy. Ask students what they notice.
    - The ruler is reading larger measurements than it should. For example, the 1" side is measuring a little over 1.3", the 2" side is measuring a little less than 2.7", and the 3" side is measuring a little less than 4".
- Explain that the provided ruler's increments between 0 and 12 are actually 9 inches. Explain to students that all tools should be calibrated and zeroed before use to ensure they provide accurate readings.
- Direct students to find their calipers.
- Explain that the caliper is a high precision measuring device that can measure to the nearest thousandth of an inch or hundredth of a millimeter.
    - Review the caliper parts and how to use it: Explain that there are two main jaws that we will use to measure external distances and internal distances. The larger bottom jaws are for external distances and the smaller top jaws are for internal distances. Show that the device should read 0 when the jaws are closed and touching. Explain that to get the most accurate and precise measurements we need to make sure that the item we measure is perpendicular to the jaws. Explain that the jaws do not need to be squeezed hard or hold the item with any excessive force, but should firmly hold either side of the item.
- Direct students to ensure that their device is accurate by checking it with the 1-2-3" block.
    - If students see that the readings are decimal places off, explain that every device has some amount of error. These devices are accurate ± 0.001"/ 0.02mm.
- Direct students to use the calipers to remeasure the lengths and diameters of the pins. Measurements should be recorded in mm to two decimal places in table 3.
- After students have all taken their measurements for the three pins, have students share their length/diameter for each pin and record it in the provided spreadsheet.
- Ask students to compare the averages and standard deviations to the measurements taken with the ruler.
    - Standard deviation is much smaller now, and the averages are very different now because the device is accurately measuring.
- Explain the pins provided should have the following dimensions: 4mm x 30 mm, 5mm x 35mm, and 6mm x 30mm.
- Ask students why their measurements are different from the advertised values?
    - It's impossible to make every product exactly the same every time. There's machine error and measurement error to account for.

- Explain that errors can occur due to the measurement equipment (every tool has a certain accuracy and precision) and the tooling equipment (CNC machine, laser cutter, mills etc).
    - The manufacturer's goal is for the average to be very close to the advertised value and for standard deviation to be small. The standard deviation tells us the tolerance that they allow on the manufacturing line. Though nothing will be created perfectly every time, we can set limits to how far from perfect we can stray while still allowing the product to function as needed. Tolerance values are generally determined by the machine being used and the function needed for the part.

Part 2: Determining Fit (10-20 minutes)

- Explain that when parts need to fit together, tolerances become even more important. Explain the following scenario: part A is a pin and part B a hole. If the tolerance is too loose (large), then when part A is at its largest tolerated size and part B is at its lowest tolerated size, the two may not come together as we intend.
- Explain that engineers work to ensure that part tolerances are defined to ensure fit and function in addition to small amounts of wiggle room. Without wiggle room, many produced parts might be discarded resulting in a loss of material, money, and time.
- Explain that fits can vary depending on the function needed in product. Two examples of fits are clearance fits and interference fits.
- Ask students what they think a clearance fit means? What does it mean to clear something (especially in sports like high jump)?
    - A clearance fit means that the parts do not touch as there is some gap between them. One part can fit into the other and slide right through.
- Ask students what they think an interference fit means? What does it mean to interfere (especially in sports like football)?
    - An interference fit is a tight fit that relies on friction. The pieces have to be pushed together and may be hard to remove after pressed.
- Direct students to find the acrylic tolerance block at their station.
- Explain to students that they will be evaluating the fit of their metal dowel pins with a variety of hole sizes. Students should test their pins in the holes and make observations about how much play was allowed with each pin/hole combination. Did the block spin on the pin when rotated? Freely? Every few turns? Was it able to pass through the hole? How much force was needed?
- By the end students should be able to make recommendations for a hole size based on the function needed in a toy. Students can use their calipers to measure the size of the hole that should be used with each pin.
- Explain that the skills they used in this activity and the knowledge they acquired/honed are essential to a career in metrology. Explain that the manufacturing industry needs metrologists in their quality control and quality assurance departments and that many machinists need a deep understanding of these areas as well to succeed.