Metrology

Educator's guide (student guide and all documents also at sites.ieee.org/albuquerque)

Overview

Metrology is the science of measurement. Measurement standards are found in the earliest written documents from Sumeria. Metrology is a foundation for science, for engineering, and for commerce.

Key Concepts

- What makes a good measurement?
    - Measurement is a comparison
    - Understanding that there is uncertainty in measurement
    - Understanding the sources of uncertainty
- What is calibration?
    - Understanding the comparison to a better standard, and ultimately back to the SI system

Learning Objectives

- Measurements of physical properties (quantities)
    - Different physical quantities, such as length and force
- Uncertainty in measurements
- Calibration of a measurement instrument (applying the methods of the engineering design process)

Key Terms:

Physical Property
Measurement
SI
Quantitative Observation
Scale
Traceability
Mass
Pounds
Newtons
Standardization
Engineer

Time Requirements: Two 60 minute class periods
Suggested Audience: Grades 6-8, will need to be adapted for lower grades
Prior Knowledge: Experience with a ruler, different scales of measurement, measuring linear quantities, and the Metric System. Force is measured in this investigation, however, it is possible to use the investigation to introduce applied force and measurement.

Curriculum Connections

Next Generation Science Standards
(https://www.nextgenscience.org/overview-topics)

Disciplinary Core Ideas:
(MS-PS1-1) Develop models to describe the atomic composition of simple molecules and extended structures.
(MS-PS2-2) Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.
(MS-PS2-5) Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation.

Cross-Cutting Concepts:
(MS-PS1-1) Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
(MS-PS1-3) Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.
(MS-PS1-3) Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.
(MS-PS2-3),(MS-PS2-5) Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Science and Engineering Practices:
(MS-PS1-1),(MS-PS1-4)Develop a model to predict and/or describe phenomena.
(MS-PS2-2),(MS-PS2-4)Science knowledge is based upon logical and conceptual connections between evidence and explanations.

Common Core State Standards for Science and Technical Subjects:
(http://www.corestandards.org/ELA-Literacy/RST/6-8/)
RST.6-8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-PS1-1),(MS-PS1-4)
RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. (MS-PS2-1),(MS-PS2-2),(MS-PS2-5)
MP.2: Reason abstractly and quantitatively. (MS-PS1-1)
MP.4: Model with mathematics. (MS-PS1-1)

Background Information:
Engineering starts with a problem. Tell the students what needs to be discovered, and that it is up to them to design and test the procedure to solve the problem.

Lab Description:
We need to measure the geometry of the chocolate and the test equipment using a ruler, and we need to measure the force that breaks the chocolate. How do we know our measurement instrument is good?

Problem:

Your client needs to find the various strengths of chocolate. They want to know which chocolate is the strongest. (Perhaps they want to build a chocolate house that the big bad wolf can't blow down?)

Sub-Problems:

1. What do you define as "strength"?
2. How are we going to test this? With what?
3. How will be we be consistent?
4. How do we contain the chocolate? (No 3-second rule!)

Different Engineering Viewpoints:

- Design Engineer: Designing the apparatus
- Mechanical/Structural Engineer: Geometry considerations
- Material science: Composition, fracture description, etc.
- Measurement Scientist: Measurement scientists are called "metrologists" (TMI: No US degrees in metrology; metrologists generally start out as engineers or scientists)
    - Engineers change fields--they don't do the same thing their whole career

<u>Materials & Supplies:</u>

- Length measurement:
    - "official" ruler (teacher supplies this)
    - Various US coins (pennies, nickels, dimes, quarters)
    - Cut-up photocopies of rulers at different magnifications (90%, 95%, 100%, 105%, 110%)
- Force measurement:
    - Luggage scale (an electronic luggage scale, such as the Dr.Meter ES-PS01, about $10 at amazon.com, is suitable for this. Fishermen's scales are also good. You want a scale with 5 kg capacity, and as good a resolution as available), or a spring scale (fishing scale)
    - Classroom balance and weight set (option 1)
    - 10 rolls of nickels (40 nickels/roll; $2 per roll of nickels) (option 2)

Pre Lab:

<u>*Discuss:*</u> **What are standards**? Standards refer both to documentary standards, such as rules and regulations, and to measurement standards, which are references used in establishing accepted values for units of measurements.

Some things for which there are standards: The size of a roll of toilet paper. Have students discuss other things that have standards in the classroom or in the home. (Example: the size of electrical outlets; the voltage of batteries). Ask students why these items have standards, and who are the people who care (example: any roll of toilet paper from any store can fit in the toilet paper holder; manufacturers and industry, in order to make commerce and trade easier)

Measurements of physical properties and their quantities (quantitative observations): What are physical quantities? They are not abstract, but have tangible properties. Our senses sense physical quantities. Some example physical quantities that we measure are temperature and length. These have standards to help define them. Things that are not physical quantities: Abstracts are not physical quantities; the beauty of a painting is an abstract quantity. Have students discuss what good characteristics of standards are. (Example: useful, does not depend on a single unique item, i.e. universal)

Discuss **traceability—the idea that measurements follow a hierarchy to international agreement**. The US signed the "convention of the meter" treaty in 1875, and at the most accurate level of measurements, uses the SI system (commonly called the metric system). The most accurate measurements are made using fundamental properties in physics.

Traceability is a legal definition where each measurement is linked to a more accurate measurement, and ultimately, to internationally defined standards.

The "customary" units in use in the US (inch, pound, degree fahrenheit) trace to the SI.

US coins have nominal specifications (the US mint states that newly minted coins should meet these specifications) (student handout).

Discuss **abbreviations used** (g=gram; in.=inch; mm=millimeter). On luggage scale, kg=kilogram, 1 kilogram = 1000 gram

Coin Specifications

https://www.usmint.gov/learn/coin-and-medal-programs/coin-specifications

The following table gives specifications for The United States Mint legal tender coins presently in production for United States Mint Annual Sets.

Denomination	Cent	Nickel	Dime	Quarter Dollar	Half Dollar	Presidential $1	Native American $1 Coin
Composition	Copper Plated Zinc 2.5% Cu Balance Zn	Cupro-Nickel 25% Ni Balance Cu	Cupro-Nickel 8.33% Ni Balance Cu	Cupro-Nickel 8.33% Ni Balance Cu	Cupro-Nickel 8.33% Ni Balance Cu	Manganese-Brass 88.5% Cu 6% Zn 3.5% Mn 2% Ni	Manganese-Brass 88.5% Cu 6% Zn 3.5% Mn 2% Ni
Weight	2.500 g	5.000 g	2.268 g	5.670 g	11.340 g	8.1 g	8.1 g
Diameter	0.750 in. 19.05 mm	0.835 in. 21.21 mm	0.705 in. 17.91 mm	0.955 in. 24.26 mm	1.205 in. 30.61 mm	1.043 in. 26.49 mm	1.043 in. 26.49 mm
Thickness	1.52 mm	1.95 mm	1.35 mm	1.75 mm	2.15 mm	2.00mm	2.00 mm
Edge	Plain	Plain	Reeded	Reeded	Reeded	Edge-Lettering	Edge-Lettering
No. of Reeds	N/A	N/A	118	119	150	N/A	N/A

Content last updated on September 20, 2016

ISO 7810:2003 (reaffirmed 2013)

ID-1 (drivers' licenses, credit cards, ATM cards): 85.60 mm × 53.98 mm × 0.76 mm
(~ 3.370 in × 2.125 in × 0.030 in)

Pure water has a density of approximately 0.998 kg/liter at 20°C

Lab Activities:

Part 1, Length: Using the supplies provided, identify which rulers you would want to use to measure the length, width, and thickness of the chocolate bars for the lab. Use the following steps:

- Devise a procedure. What do you define as an "acceptable or useful" ruler or an "unacceptable" ruler?
- Test the procedure
    - Does your procedure test different portions of the ruler? How many portions? Why is it important to test this?
    - Does your procedure include different students conducting this test?
    - Does your procedure use different sets of coins, or the teacher's ruler? Why do should you care?
    - How does your procedure differentiate "acceptable" from "unacceptable"?
- Implement the procedure
    - Note your quantitative (measured) observations
- Could you improve your procedure?
    - Note improvements that can be made
- Clarifying the procedure: If you handed your procedure to a different team, would they be able to perform the procedure, *and* obtain the same results you did?

Part 2, Force: Using the supplies provided, come up with a method to test whether or not the luggage scale or spring scale is suitable for measuring the breaking strength (how much force is applied before it breaks) of chocolate. Use the following steps:

- Devise a procedure. What do you define as "acceptable performance" for the luggage scale?
- Test the procedure
    - Does your procedure test different amounts of force? Over what span of force? Why is it important to test this?
    - Does your procedure include different students conducting this test?
    - Do you think you can make a graph? Is that useful?
    - How does your procedure establish "acceptable" from "unacceptable"?
- Implement the procedure
    - Note your quantitative (measured) observations
- Could you improve your procedure?
    - Note improvements that can be made
- Clarifying the procedure: If you handed your procedure to a different team, would they be able to perform the procedure, *and* obtain the same results you did?

Helpful Hints:

The process shown here mirrors the engineering process. We have established a need (to make measurements that match agreed-upon standards). The students devise possible solutions, test them, and document the results. The students also suggest improvements.

Length/dimensional (linear) calibration: An acceptable limit might be ±1 mm over a 50 mm span. The students could choose not to use the coins directly, but trace the coins on paper, and use the marks. They could make a similar choice with the teacher's rulers. They could use the teacher's ruler to measure a post-it note, or an index card, or some other object—and then test the unknown rulers against the post-it or index card. There are a number of approaches which would work.

Force calibration: Luggage scales and spring scales are really force scales, and do not measure mass; however, they report results in units of mass. It is worth discussing briefly that there is a difference between force and mass, but for the purposes of this exercise, stating that you are measuring force using grams and kilograms is fine.

An acceptable limit might be ±10 g over a 500 g span. If the school has a weight set, a 1 lb weight is approximately 453.59 g. An unused nickel is 5 g, so a roll of nickels (without the wrapper) will be approximately 200 g. Note that the digital luggage scale reads in kg, so the students will need to convert the reading from kg to g (multiply by 1000, or move the decimal point over to the right by three places). If you don't have 200 nickels (to get to 1 kg), and no calibrated 1 kg weight, you can be clever: You can use 40 nickels (200 g) and find another object that weighs 200 g. Repeat this process with multiple objects that add up to 1000 g. (There are some statistical subtleties why this is not as good as having a calibrated 1 kg weight, but it's a clever approach if you have no heavy calibrated weights).

In the classroom, students would get more precise results by putting individual nickels (or nails, or similar objects) until the chocolate breaks. They can count nickels (or nails, etc.), or they can weigh the container with all the nickels after the chocolate breaks. A similar approach is to hang an empty 2-liter soda bottle, and fill the bottle until the chocolate breaks. Weigh the container that you used to fill the bottle before you start, and after the chocolate breaks—this tells you how much water you used! (and don't forget to devise a method to contain the mess! This could be another structured design exercise!)

Further Explorations

- Use the luggage scale to measure students' backpacks, and compare with using a bathroom scale.
- Compare triple beam balance, Newtonian (spring) scale, luggage scale, and electronic balance as a calibration exercise.

Related Resources

- Online resources will be added to the electronic document stored in the Albuquerque IEEE website (http://sites.ieee.org/albuquerque)
- The original document that inspired this exercise is from the American Ceramics Society; www.ceramics.org then search for "Chocolate Strength – How Strong is Your Chocolate" The formula for "flexural strength" is excerpted from that document below. The unit N is newton and is the SI unit of force: A mass of 98 g has a gravitational force of about 1 N at the surface of the earth. A pascal is a unit of pressure (force applied over an area=force divided by area); MPa stands for "megapascal"; 1 MPa=10^6 N/m^2. Flexural strength is a physical material property. In theory, different sizes of test bars made of the same material will still have the same flexural strength.
- The website "tryengineering.org" has a lot of good resources for other lesson plans
- NIST (www.nist.gov) has teacher resources for measurements and the SI system: This direct link https://www.nist.gov/pml/weights-and-measures/si-teacher-kits-available-educators may be useful. Also check out https://www.nist.gov/kids
- NCSLI (www.ncsli.org) is active in outreach in metrology education.

Carolina Biological Supply (www.carolina.com, one of the STEM symposium sponsors) carries science supplies for the classroom, including electronic balances and spring scales

Nasco (www.enasco.com) is another good supplier of STEM supplies

Harbor Freight Tools is an inexpensive resource for electronic balances, but they don't take school purchase orders.

Amazon.com has many tools available, but finding what you're looking for can be difficult.

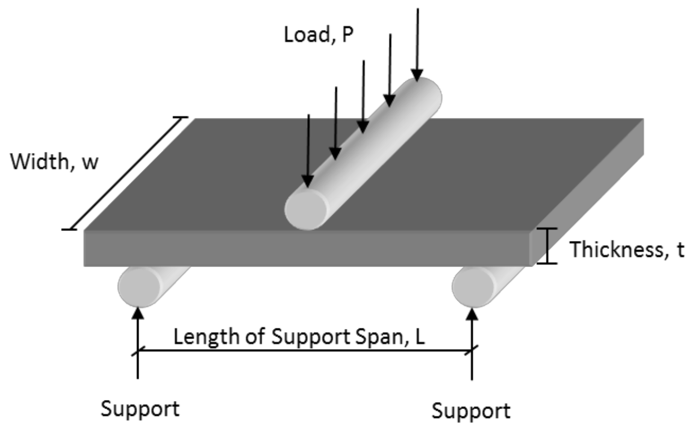

Figure 1. Test set-up for a 3-point bending test

For this test set-up, chocolate bars are placed on two supports (making 2 points of contact), and a force is applied to the center of the bar (making the 3rd point of contact in the 3-point bending test). The flexural strength of the bar is essentially the highest stress that the material experiences during its moment of rupture (failure) and can be calculated from the following equation:

$$\sigma = \frac{1.5PL}{wt^2}$$

where σ is the flexural strength (MPa), P is the applied force (N), L is the span length (mm), w is the width of the bar (mm), and t is the thickness of the bar (mm).