Chapter 01: What is Science? *Physical Science*, Tillery, 13th ed.

Lab 01: Estimates and Measurements DUE: 18 Jan 2024

Introduction

Making measurements is fundamental to science: geologists measure the age of rocks, astronomers measure the distances to the stars, biologists measure the rates of cell metabolism, physicists measure the masses of subatomic particles. Because measuring is so important, we need to have a good understanding of how measurements are made, and the unite we use to give them context. This week we will practice using the metric system and making some simple measurements.

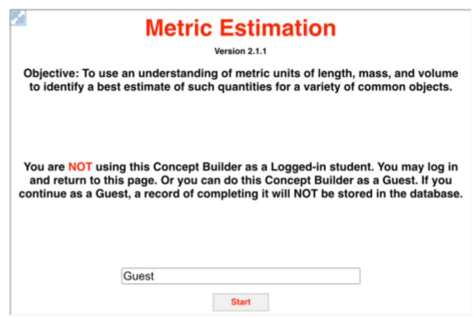
A ruler is typically precise to 1/16th of an inch.

We also need to spend a minute (or two) thinking about a few other related concepts. Significant digits, for example. When you perform an operation using your calculator and get a result with nine decimal places, do you write them all down? Do you automatically think that more decimals = better? What if I told you that most of the time most of those decimal places are meaningless?

Another example: we tend to think that precision and accuracy mean the same thing, and we probably use the words interchangeably. However, they do represent separate and distinct concepts, so we need to have a clear definition for and understanding of each.

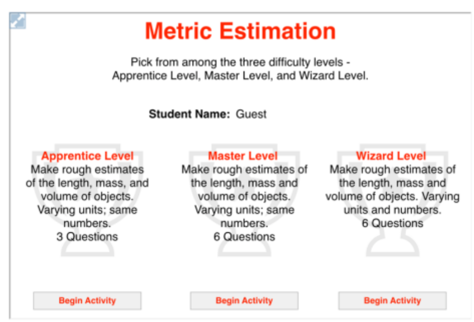
Objectives

- Become familiar with using the Physics Interactives interface
- Practice the process of making numerical estimates
- Understand the difference between precision and accuracy in measurement
- Learn to make reliable and repeatable measurements
- Practice recording data and information in a structured format



Equipment

- Internet-connected device capable of running a browser
- Paper and pen or pencil (you're always going to need these)
- Scientific calculator
- Patience and a sense of humor (you're going to need plenty of both)



Procedure

1. Read this handout completely before you try to dive in. It will save you time and frustration later. If you are able to print it, you will not have to tab between windows—you can look at this and the simulation at the same time.
2. Do you have paper and pencil handy? Don't forget your calculator.
3. Do you need a little review on the metric system? You can start with the Metric System Concept Builder to review the basics (which are also covered in the text).
4. In a browser window, navigate to the Metric Estimations Concept Builder. Don't try to start doing the lab yet! Just verify that when you click LAUNCH the interactive opens properly.

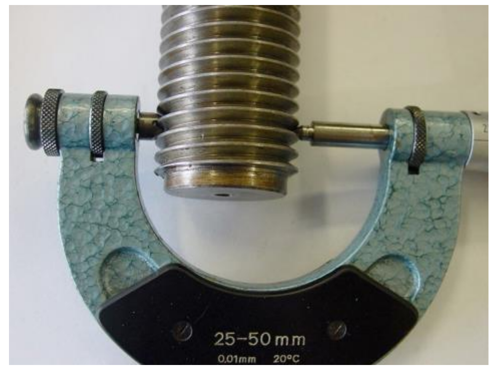
Metric Units and Estimations

You should proceed with the Metric Estimations exercise as GUEST. No need to log in. There are three levels of difficulty, with a few questions at each level. You should begin at APPRENTICE LEVEL and work your way through WIZARD LEVEL. Once you have, you should be able to answer the questions below easily.

1. When you look in the pantry, you notice that a box of spaghetti is labeled as 1 pound (454 grams). The jar of marinara sauce is labeled as 24 ounces (680 grams). The metric units are consistent: both list mass in grams. Why are they different in English (Imperial) units?
   A) Because in the Imperial system, ounces can be used to measure either volume or weight. No confusion there, right?
   B) Because the pasta is dry and the sauce is wet. Things have different mass depending on their state (solid, liquid, or gas).
2. Why did I just ask you that question above?
   A) Because it's almost dinner time and you are thinking about what to cook for supper?
   B) To illustrate one of the (many) inconsistencies that make the Imperial system much more difficult to use.
3. To measure the size of a sheet of notebook paper, which units are the most appropriate scale? The size of the unit should be similar (not too big or too small) to the object being measured.
   A) Millimeters = 0.001m B) Centimeters = 0.01m C) Kilometers = 1000m

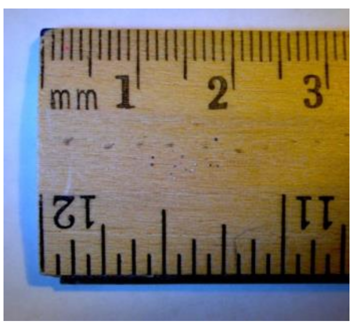
4. Estimate the length l of a standard sheet of notebook paper.
   A) $l = 28\text{nm}$
   B) $l = 28\mu\text{m}$
   C) $l = 28\text{mm}$
   D) $l = 28\text{cm}$
   E) $l = 28\text{m}$
   F) $l = 28\text{km}$
5. If you are measuring the mass of an apple and the mass of a football player, are the same units most appropriate?
   A) Sure. Mass is mass, so what's the big deal? Besides, there's only one possible unit to use: milligrams.
   B) Maybe…if the player eats the apple and you want to calculate the increase in his mass, use the same units: kilograms.
   C) Nope. An apple would be measured using grams, but the person would be measured using liters (or maybe kiloliters).
6. By now you have noticed that the sim frequently expressed the correct answer using the most inconvenient units (you know, like a door that's 0.002km tall). What was the point???
   A) There wasn't one.
   B) To distract and confuse.
   C) To encourage someone without much experience using metric units to practice them and get a better intuitive feeling for the sizes and relationships between them.

Precision, Accuracy, and Uncertainty



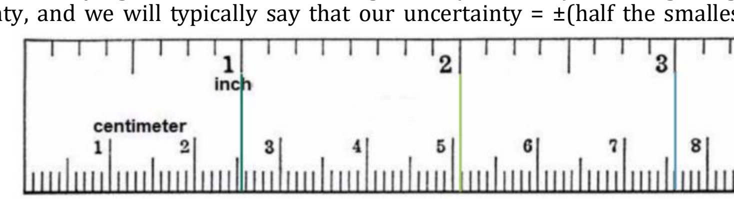
A carpenter building a house needs to be precise to ⅛, or maybe 1/16 of an inch. So a tape measure or T-square marked in inches, subdivided down to an eighth or sixteenth of an inch is an adequate tool for him to use. But a machinist milling parts for a jet engine will need a more precise measuring tool—something that can measure much smaller increments, down to a thousandth or even a ten-thousandth of an inch. The carpenter's ruler simply isn't going to be useful to him. However, just because the ruler is less precise than the machinist's micrometer does not automatically mean that the machinist is more accurate!

While precision is an inherent property of a measuring instrument, accuracy is related to the use of that tool. A machinist with a very precise micrometer can still make an inaccurate measurement—what if he has aligned the tool improperly, or read the dial incorrectly, or done something otherwise careless? The carpenter, using a less precise tool may be more accurate, if he is using his instrument properly and making his measurement carefully.



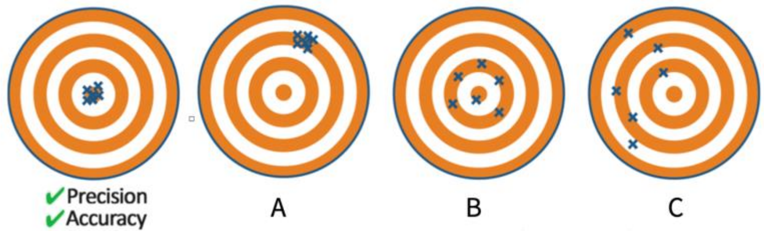
7. Examine the ruler on the left (or a real ruler, if you have one handy). The smallest division on the metric side is 0.1cm, or 1mm. The smallest on the Imperial side is $\frac{1}{16}\text{in}$, or 0.0625in. Which scale is more precise?
   A) Centimeters, because you can clearly see that the space between the tick marks is smaller.
   B) Inches, because you can clearly see that 0.0625 of an inch is a smaller fraction than 0.1 of a centimeter!
   C) Trick question; precision is unrelated to the markings on the measuring tool.
8. Let's say two people use the same ruler to measure the same object, but one person uses inches and the other uses centimeters. Can the person using the less-precise scale make a measurement that's more accurate?
   A) Nope. Using the less-precise scale automatically makes the measurement less accurate.
   B) Maybe…if the person using the more precise scale is unfamiliar with how to use the tool, they might not use it correctly.
   C) Always. Accuracy and precision are inverse: the greater the precision, the smaller the accuracy. And vice-versa.

Let's take a minute here to think about the limits on our precision. That ruler can measure a length in centimeters accurately to the nearest 0.1cm. But what if an object's length falls between two tick marks? Happens all the time. Now what? Well, now you have an uncertainty in your measurement (notice I did not say error—nobody made any mistakes). If the object's length is close to the midpoint between ticks, you'd probably feel more comfortable saying $l = 2.35\text{cm}$ than calling it low ($l = 2.3\text{cm}$) or calling it high ($l = 2.4\text{cm}$). But we need to acknowledge that uncertainty, and we will typically say that our uncertainty = ±(half the smallest division) on whatever tool we are using.



Examine the ruler on the right. Notice the lines at the 1–, 2–, and 3–inch marks. None of them fall exactly on a tick on the centimeter side of the ruler!

9. What's the correct way to express the position of the 1 inch line in centimeters as marked on the ruler?
   A) $2.50\text{cm} \pm 0.05\text{cm}$
   B) $2.55\text{cm} \pm 0.05\text{cm}$
   C) $2.60\text{cm} \pm 0.05\text{cm}$
   D) $2.50\text{cm} \pm 0.50\text{cm}$
   E) $2.55\text{cm} \pm 0.50\text{cm}$
   F) $2.60\text{cm} \pm 0.50\text{cm}$
10. How about the positions of the 2– and 3–inch lines?
    A) You should never try to estimate a second decimal place, even if the marks are dead center between the ticks on the ruler.
    B) You should always try to estimate the second decimal place as close as you can, like 5.09cm or 7.61cm. If you can estimate a third decimal place, that would be even better, like 5.095cm for the 2–inch mark and 7.605cm for the 3–inch mark.
    C) If the mark is dead center (or close to it) between ticks, go ahead and estimate the second decimal. But for the 2– and 3–inch marks, they are both definitely closer to a tick than center. The 2–inch line is at 5.10cm and the 3–inch at 7.60cm.



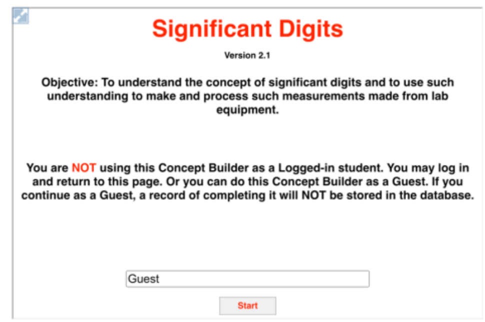
Here's another way to look at precision and accuracy. If you are aiming for the center of the target, accuracy would be getting all your shots in the bull's eye, right? What does precision mean in this context? Precision would be putting the second arrow through the hole in the target made by the first arrow (or as close to the hole made by the first arrow as possible), regardless of where that first hole was.

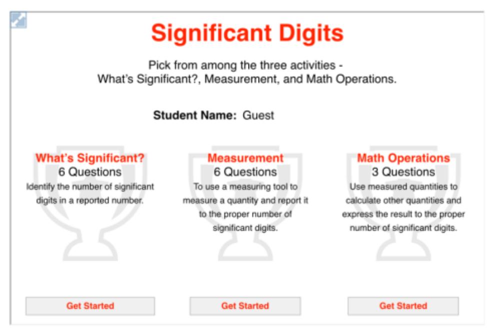
Now take a look at the groupings labeled A, B, and C. Accurate? Precise? Both? Neither?

11. Grouping A is
    A) accurate, not precise. B) precise, not accurate. C) neither accurate nor precise.
12. Grouping B is
    A) accurate, not precise. B) precise, not accurate. C) neither accurate nor precise.
13. Grouping C is
    A) accurate, not precise. B) precise, not accurate. C) neither accurate nor precise.

Significant Digits

Return to your browser window and launch the Significant Digits Concept Builder. Like last time, continue as a GUEST. Also like the previous simulation, there are three sets of exercises to complete. Once you have worked through all three, you should be able to answer the following questions easily. (Hint: Clicking the HELP ME! button is really useful.)





14. When you make a measurement with a typical centimeter ruler, the object lines up exactly 6mm past the 4cm mark. How many sig figs?
    A) $l = 4\text{cm}$, which is 1 sig fig.
    B) $l = 4.6\text{cm}$, which is 2 sig figs.
    C) $l = 4.60\text{cm}$, which is 3 sig figs.
    D) $l = 4.600\text{cm}$, which is 4 sig figs.
15. When you write a decimal number, you have leading zeroes. For example, 3.5mm can be written as 0.0035m.
    A) Those leading zeroes are significant digits.
    B) Those leading zeroes are not significant digits.
    C) The zero in front of the decimal is not significant (because it's optional). But the zeroes after the decimal are significant.
16. What about trailing zeroes? Are trailing zeroes significant or not?
    A) Trailing zeroes are never significant digits.
    B) Trailing zeroes are always significant digits.
    C) Trailing zeroes may or may not be significant. Simple rule: no decimal, no significant trailing zeroes.
    D) That simple rule in answer C) is not quite right. Trailing zeroes are only significant digits if the number does not contain a decimal!

You have a small box, and you have measured its length $l = 4.75\text{cm}$, its width $w = 2.25\text{cm}$, and its height $h = 2.25\text{cm}$.

17. What is the perimeter $p = 2l + 2w$ of the base of the box?
    A) $p = 7\text{cm}$ C) $p = 7.00\text{cm}$ E) $p = 14.0\text{cm}$
    B) $p = 7.0\text{cm}$ D) $p = 14\text{cm}$ F) $p = 14.00\text{cm}$
18. When you calculate the area of the base ($A = l \times w$), your calculator reads 10.687500. Are all of these digits significant?
    A) Yes. Your calculator is designed to be both as accurate and precise as possible.
    B) Almost. Those two trailing zeroes are not sig figs.
    C) No. You cannot get results that are more precise than the measurements you made! If you cannot measure more than two decimal places, you shouldn't report more than two decimal places in your results.
    D) Answer C) is not quite right. That's the correct rule for adding values. The rule for multiplying values is similar, but not exactly the same. (When you multiply, you keep the least number of significant digits, not decimal places.)
19. When you multiply numbers, you keep the least number of significant digits, not decimal places. How many significant figures should your result for the volume of the box ($V = l \times w \times h$) have?
    A) $V = 24.046875\text{cm}^3$ C) $V = 24.0469\text{cm}^3$ E) $V = 24.05\text{cm}^3$
    B) $V = 24.04687\text{cm}^3$ D) $V = 24.047\text{cm}^3$ F) $V = 24.0\text{cm}^3$