Flipping Physics Lecture Notes:
Why "Show All Your Work!"?
http://www.flippingphysics.com/show-work.html

I've been a high school physics teacher for more than 2 decades and I require you, my students, to "Show All Your Work!". I often get asked why. Today, I answer that question.

After roughly 5 years of teaching physics, I decided to start making you show more and more of your work. Y'all fought back against it and continue to this day to do so, however, I can tell you that you, my students, understand what you are learning so much better now that you "Show All Your Work!". Let's talk about why.

One of the first things I have you, my students, do is a lab which utilizes very little of what you have learned in the class and honestly, you probably could have done a couple of years ago. The whole purpose of this first lab is to make sure you can "Show All Your Work!". The first question on the lab is to take measurements using an electronic balance and a digital scale to determine the density of a steel sphere in kg/m$^3$. Here are my solutions:

$$\text{Knowns: } m = 68g, D = 25.3mm \;\&\; r = \frac{D}{2} = \frac{25.3mm}{2} = 12.65mm \;\&\; \rho = ?$$

$$V_{\text{sphere}} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(12.65mm)^3 = 8479.3mm^3$$

$$\rho = \frac{m}{V} = \frac{68g}{8479.3mm^3} = 8.0195\times10^{-3}\frac{g}{mm^3}\left(\frac{1kg}{1000g}\right)\left(\frac{1000mm}{1m}\right)^3 = 8019.5\frac{kg}{m^3} \approx 8.0\times10^3\frac{kg}{m^3}$$

- I listed the values I measured as my knowns.
- I wrote down the equation relating radius to diameter and used it to determine the radius.
- I wrote down what we are solving for.
- I wrote down the equation for the volume of a sphere, substituted in a number for radius, and wrote down the number, with 5 significant figures, for the volume of the sphere, including units.
- I wrote down the equation for density, substituted in numbers for mass and volume, solved for the density in g/mm$^3$, converted to kg/m$^3$, and then rounded to 2 significant figures because the least number of sig figs from our knowns was the mass at 2 sig figs.

Here is a reproduction of solutions I received from students:

$$0.068kg, 12.65mm, \frac{4}{3}\pi(12.65)^3 = 8.02\times10^{-3} \;\&\; \frac{0.068}{8.02\times10^{-3}} = 8.0\times10^{-3} = 8.0x10^3\frac{kg}{m^3}$$

Please notice the following:

- None of the known values are identified.
- The electronic balance measured the mass of the steel sphere in grams; however, the student converted the mass to kg without showing that conversion.
- There is no way to measure the radius of a sphere with a digital scale. First you need to measure the diameter of the sphere, then you can determine its radius.
- The equations for volume and density were never shown.
- The volume of the sphere was rounded even though volume is not an answer and no units for volume were given.
- A conversion is missing: $8.0195 \times 10^{-3} \neq 8.0 \times 10^3$ (and no units were shown)
- The unrounded density is missing.

Before students can turn in their first lab in my class, I require them to go through their solutions to the lab with me so we can discuss how well they did and the whole "Show All Your Work!" thing. With a solution like the above, it is not unusual for students not to be able to describe what they did. With a solution where all the work is shown, you do not have to remember because everything is there!

A few subtle points:

- I often see something like this for a solution for radius from diameter:
  - $$D = 2r = \frac{25.3mm}{2} = 12.65mm$$
    - Notice the middle equal sign is not correct.
  - The following is a correct solution:
  - $$D = 2r \Rightarrow r = \frac{D}{2} = \frac{25.3mm}{2} = 12.65mm$$
  - The essential difference is that, when equations on both sides of the sign are not equal to each other, an arrow symbol is used for separating steps instead of an equal sign. The arrow indicates that one equation can be rearranged to form the next equation.
- I require you to write out an equation right before you use it.
  - "But the equation is written at the top of the page?" is a rebuttal I often hear.
    - There are going to be many, many equations in this class. You absolutely need to get used to showing exactly which one you are using as you use it.
  - Writing an equation out *after* you use it skirts the whole point of writing the equation down in the first place. The reality is that the act of writing out known variables and equations before you use them is a part of the physics thinking process. Usually when you start solving a problem, you do not know what the solution will be. Writing down equations and known values are helpful ways of processing information, will help streamline your thinking, and helps you figure out what the solution is.
    - I am trying to help you build good problem-solving habits for more difficult and longer problems in the future.
- You need to substitute numbers into your equations, even though you have already written those numbers down. This decreases mistakes and illustrates what you actually did.
- Every ending number in your solution must have units.[1,2]
- You need to show conversions. Soooooo many mistakes are made because students incorrectly convert a number. Showing the conversion mitigates these mistakes.
- Always write out the unrounded answer before you round. You are less likely to make mistakes when you do this, and you might need the unrounded number later. (Yes, it is needed later in this lab.)

Another example of part of this solution which I often see from students is the following:

$$r = \frac{D}{2} = \frac{25.3}{2} = 12.65^3 \left(\frac{4}{3}\right)\pi = 8479.3mm^3$$

What is usually happening here is that the student has correctly solved for the radius of 0.955 cm, however, they then think, "Oh, I'm solving for volume!" and plug in numbers to solve for volume. This makes this equation no longer correct. A corrected version of this is:

$$r = \frac{D}{2} = \frac{25.3}{2} = 12.65mm \;\; \& \;\; V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(12.65)^3 = 8479.3mm^3$$

This solves for radius, then solves for volume.

So, to answer the question "Why do I require you to 'Show All Your Work!'?", it is to help you learn more efficiently. As you get further and further into your physics learning, the situations you will be analyzing will become more and more complex, and all of the topics will build on one another. This means your solutions will get longer and longer and longer. If you learn how to "Show All Your Work!" at the start of your physics learning, you, and others, will be able to follow your work, you will learn more efficiently, and you will be happier physics students. And that is what I want for you, to be happy physics students. So, please, please, please, "Show All Your Work!"

---

[1] Eventually we will get to some numbers which do not have units; however, I'll make that very clear when it occurs!

[2] I do not require units on all numbers in the middle of equations. It gets too cumbersome.