Lesson 5: Accuracy and Precision

Introduction

This document is Lesson 5 of the SEAChem2020 open source chemistry curriculum program for secular homeschoolers. This version was current as of 28 August 2017. To if there is a more current version of this document, visit www.SEAChem2020.org.

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- **Let us know about minor fixes**. If you find anything from a factual to a stylistic error, or even a typo, let us know by using this form.
- **Let us know if you find big problems**. Does something need rewriting? Let us know by contacting us using this form.
- **Give us your resources**. If you've done one of these lessons and have put something cool together, email us at misterguch@chemfiesta.com so we can include it!
- **Volunteer**. Do you want to edit this curriculum? Do you have things to add? Would you like to write some of these lessons? Let us know!
- **Publicity**. Tell your friends about these resources. When the community grows, the project keeps growing!

Thank you for using this resource, and please consider helping out!

Lesson 5: Accuracy and Precision

Parent Reference

Objective: To learn what accuracy and precision are and to learn how to use them in scientific measurements.

This lesson contains the following:
- Text: Accuracy and Precision
- Lesson glossary
- Practice sheet
- Activity: Making Measurements
- Assessment
- References for further study

Additional resources needed: None

How to use this material:
This lesson is set up to be used in the following way. During the course of this lesson, your child should:

- Read the material in the text.
- Rewrite the material in their own words. (Optional but recommended).
- Complete the practice sheet.
- Write their own practice sheet for the material, complete with answer key. (Optional but recommended).
- Complete the activity.
- Write their own activity for the material, with suggestions on how to best to complete it. (Optional but recommended).
- Take the assessment to ensure they understand the material.
- Write their own assessment, along with solutions. (Optional but recommended).

These steps should be followed by a debrief, in which you and your child will discuss the material. Any suggestions you have to improve this lesson, as well as any materials your child writes during this lesson (text, practice, activity, assessment) should be sent to SEAChem2020 so that we may incorporate it into the curriculum.[1]

Practice Sheet:
This practice sheet is a mixture of both rote definition questions that universities will assume incoming students should have and open-ended problems that challenge your child to think creatively (which is what universities *really* want). When your child is finished with the practice sheet, we recommend that they spend a few minutes writing their own practice sheet. Teaching is the best way to learn something, and by teaching others your child can help to teach him/herself. Please submit any practice sheets to SEAChem2020 at misterguch@chemfiesta.com.

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Activity:
The information about the activity is included within the activity itself.

Assessment:
The assessment in this lesson, as in all of the lessons, is meant to not only indicate whether your child has learned the material, but to push them to think even further than they have before. After all, assessments should be part of the learning process, too. When your child is finished with the assessment, we recommend that they spend a few minutes writing their own assessment. Teaching is the best way to learn something, and by teaching others your child can help to teach him/herself. Please submit any assessments to SEAChem2020 at misterguch@chemfiesta.com.

Lesson 5: Accuracy and Precision

You've probably heard of the terms accuracy and precision. You've probably also used them pretty much interchangeably. If my height is 180 cm and somebody guesses that I'm 180 cm tall, I'd probably say that their guess was accurate. Likewise, it wouldn't be weird for me to answer "precisely!" Accuracy and precision must be the same thing, right?

As it turns out, no. Let's have a look. In a measured value:

Accuracy is a measure of how close your measurement was to the actual value of the thing you're measuring. If I were to say that my cat weighs 4 kg and it *does* weigh 4 kg, my guess is accurate. If I had guessed it weighed 6 kg, it's less accurate.

Precision is a measure of the variability of a measurement. Let's say, for example, that there were 50 birds in my front yard. If I looked out the window and guessed that there were 80 birds, my wife might say "are you sure about that?" If I then looked out the window and said, "yep, looks like 80" then we would say that my measurement was precise because I reproduced the same answer I got before. Note that my guess, while precise, was not accurate because I didn't guess the correct answer of 50 birds.

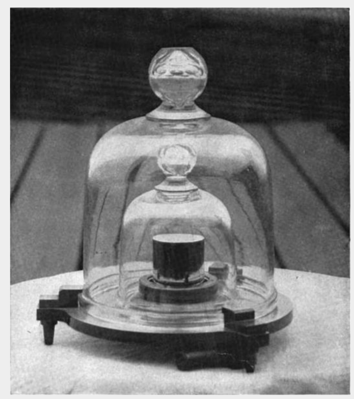
How can we tell whether a measurement is accurate?

*It's hard to know the accuracy of a measurement. After all, we wouldn't have taken the measurement if we already knew the actual value. To figure out whether our measuring device is accurate, we calibrate it with a **standard**, which is something with a known value. For example, if a balance accurately finds the mass of a 1.00 kg weight, it's probably accurate in other measurements.*

*To indicate the accuracy of a measured value, we refer to the **percent error** of a measurement:*

$$\% \text{ error} = \frac{error}{actual\ value} x\,100 \quad \%$$

As a result, if we measured the width of a penny as 18.7 mm and the actual width is 19.1 mm, the percent error would be (0.4 mm)/(19.1 mm) x 100% = 2%



This metal block is one of two official standard kilograms in the United States. It is very rarely taken from storage, as routine handling can slightly affect its weight.

When looking at experimental data, there is no easy way to tell how accurate or precise the data are. After all, if you were to look at a sheet of paper that says a car weighs 1,200 kg, you have no way of knowing whether my car *actually* weighs this much, or if I'd get the same answer if I weighed it again. It may sound like we're doomed to working with bad data, until we consider our next concept.

Significant Figures

Significant figures are the digits in a measured value that give us information about the precision of the measurement. This may not make much sense at first, so let's look at some measurements I took when weighing myself[2]: 90 kg, 90. kg, 90.0 kg, and 90.00 kg. Your first thought may be that I just spat out the same number four times. After all, if I were to put these numbers into a calculator, they'd all behave in exactly the same way.

However, even though these numbers mean exactly the same thing to a mathematician, there's more information to be had in how they're written. Consider this:

Measured number	What it means
90 kg	This measurement is rounded to the nearest 10 kg. The measured weight is closer to 90 kg than it is to 80 kg or 100 kg.
90. kg	This measurement is rounded to the nearest 1 kg. The measured weight is closer to 90 kg than it is to 89 kg or 91 kg.
90.0 kg	This measurement is rounded to the nearest 0.1 kg. The measured weight is closer to 90.0 kg than it is to 89.9 kg or 90.1 kg.
90.00 kg	This measurement is rounded to the nearest 0.01 kg. The measured weight is closer to 90.00 kg than it is to 89.99 kg or 90.01 kg.

In a mathematical sense, these zeros mean nothing. However, to us, the zeros at the end of this number tell us about the precision of the equipment that took the measurement. A bathroom scale that reads “90. kg” is probably as good as I would ever need, whereas on that reads “90.000 kg” would probably be overkill for figuring out whether I ate too much the night before. Generally speaking, more precise measuring tools cost more to buy and need to be maintained with better care.[3]

When working with measured data, any digits in the measured value that give us useful information about the measurement are said to be significant figures or significant digits. Here's how you can tell what digits are significant in a measured value:

1. **Nonzero digits are significant**. If you have the number 3.88 kg, all three digits are significant and give us useful information.
2. **Zeros between nonzero digits are significant**. If you have the number 3.08 kg, all three digits are significant.
3. **Zeros at the end of nonzero numbers are only significant if you see a decimal point in the number**. Two examples: 200 grams and 200.0 grams. “200 grams” has one significant figure, telling us that our measurement is rounded to the nearest hundred grams. “200.0 grams” has four significant figures because the decimal point makes all three of the zeros after the 2 significant. As a result, our measurement is rounded to the nearest 0.1 gram.
4. **Zeros in front of nonzero numbers are never significant**. If we find the weight of a bug to be 0.002 kg, we consider the zeros in front of the two to be insignificant, despite the decimal point.

2 *I didn't actually weigh myself. It's just an example.*

3 *Though there isn't necessarily any relationship between accuracy and precision, it's usually the case that people who make precise equipment usually go to the trouble to also make it accurate – after all, it doesn't make sense to tell somebody their weight to the nearest 0.01 kg if the equipment isn't very accurate.*

5. **When you use scientific notation (as in "2.3 x 10^2 grams"), we only consider the digits in front of the times sign**. In this example, there are two significant figures, rounding the number to the nearest 0.1 x 10^2 grams (or 10 grams).
6. **We only consider significant figures when working with measured values**. If we say that a bug is 15.8 mm long, this value has three significant figures. However, if we say that "there are 10 mm in 1 cm", there are an infinite number of significant figures because this is a definition and not a measurement. Similarly, if I count that there are 4 bugs on the table, we consider the 4 to have infinite significant figures because only whole numbers are possible values for this number.

> ***An unusual case***
>
> *Significant figures are, as we discussed, used to show how precise a measured value is. However, let's imagine that we have a piece of equipment that can find mass to the nearest 10 kg and it finds that the mass is 200 kg. What do we do? The number "200 kg" suggests that the value is rounded to the nearest 100 kg. The number "200. kg" indicates that it's rounded to the nearest kilogram. To get around this case, we need to use scientific notation and refer to this measurement as "2.0 x 10^2 kg", which indicates that the value is rounded to the nearest 0.1 x 10^2 kg, or 10 kg.*[4]

Using significant figures in calculations

Imagine that somebody, for whatever reason, has asked you to find the density of a piece of coal. Knowing as you do that the density of an object is equal to its mass divided by its volume, you use the equipment available to you to take the necessary measurements. When you do this, you get the following:

Mass of coal: 10 grams.
Volume of coal: 9 cm^3

To find the density, you divide the mass by the volume and find that it has a density of 1.11111111 g/cm^3. Does this make sense?

Let's examine this a little bit. If the equipment you use to find the mass of coal is only precise to the nearest 10 grams, then the true mass could be 5 grams or it could be just under 15 grams. If the equipment you used to find the volume of the coal was precise to the nearest cm^3, then the true answer could have been 8.5 cm^3 or just under 9.5 cm^3. Given that both bits of equipment give potentially lousy answers, does it really make sense to say that we can know the density of the coal to a precision of one ten millionth of a gram per cubic centimeter?

Clearly, that's not the case. As a result, we've got to come up with a way of calculating significant figures such that we give a good idea of the true precision of the answer. Here are the rules you should use when doing calculations with significant figures:

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4 *There's another way to get around this problem. The value "200 ± 10 kg" explicitly states that the value is rounded to the nearest 10 kg.*

1. **When adding or subtracting measured values, the precision of the answer should be indicated to the precision of the least precise measurement being used.**

   For example, let's say that we want to find the mass of chemical in a beaker. To do this, I can just subtract the mass of the empty beaker from the mass of the beaker with chemical inside. Let's say that I've made these measurements and see what happens:

   Weight of beaker + compound: 104.32 grams
   Weight of empty beaker: 94.7 grams

   If we do this math with our calculator, we find that the mass of the compound in the beaker is 9.62 grams. However, this doesn't really make sense. Though the first value (weight of beaker + compound) is precise to the nearest 0.01 gram, the second value (weight of the empty beaker) is precise only to the nearest 0.1 gram. As a result, our answer can't possibly be more precise than 0.1 gram, giving us an answer of 9.6 grams.

A potential problem

Let's take this to an extreme. Let's say that we combine 1.1 grams of chemical A and 0.02 grams of chemical B in a beaker. If we do the math, we find that we have a total mass of 1.12 grams. However, using the rule above, we see that the value "1.1 grams" is precise to only the nearest 0.1 gram, so we'd round 1.12 grams to 1.1 grams using the rule above. Though this seems kind of strange, it's exactly how we're supposed to do things. Here's why: Let's say that the actual mass of chemical A is 1.14, but the equipment can only see to the nearest 0.1 gram – it'll read 1.1 grams. If we add 0.02 grams to this, the answer of 1.16 grams would round to 1.2 grams. However, if we have a precision of only 0.1 grams, the value "1.1 grams" could also mean that we only had 1.05 grams of compound A. In this case, if we add 0.02 grams of chemical B, we'd round our answer of 1.07 grams to 1.1 grams. In short, the 0.02 grams of chemical B is so small compared to the uncertainty in the mass of A that we can't figure out which case we have.[5]

2. **When multiplying or dividing numbers, the number of significant figures in the answer must be the same as the lowest number of significant figures in each number in the calculation.**

   Let's go back to our original case of the coal, where we found the mass of the coal to be 10 grams and the volume to be 9 cm^3. Using this rule, we can see that both the mass of the coal and the volume have one significant figure, so when we divide the mass by the volume, the 1.11111111 g/cm^3 value from your calculator rounds to 1 g/cm^3. This isn't particularly precise, but it does accurately convey the fact that we don't really know the density of the coal to a high

5 *It may sound, then, that this addition problem can't be solved. In a lab setting, this is exactly right – the calculation above is so ambiguous that it means we won't really know what's happening in the reaction we're studying. In a case such as this, chemists would have to use more precise equipment to find the mass of A to avoid this problem. (In reality, it's hard to imagine that a chemist would use different balances for both measurements, anyway.)*

precision. In order to more precisely find the density of coal, we would need to get more precise measuring equipment.

Likewise, even if we found that the mass of the coal was 10.00 grams with a more precise balance, the very imprecise volume of 9 cm^3 means that we still wouldn't know the density of the coal with any more precision than the example above. In order to get precise answers to calculations, we need all of our experimental equipment to meet our standards for precision!

The main ideas in this lesson:

- Accuracy is a measure of how close a measurement is to the actual value. Accuracy is very difficult to determine directly.
- Precision is a measure of the variability of an experiment. Put another way, it's a measure of how reproducibly a measurement can be obtained. Precision is determined solely by the equipment used to take the measurement.
- Accuracy and precision aren't necessarily related to one another, though it's usually the case that precise measurements are more accurate than less precise ones.
- The number of significant figures in a measurement allow us to determine the precision of that measurement.
- When adding or subtracting two measured numbers, the precision of the answer is determined by the precision of the least precise measurement taken.
- When multiplying or dividing two measured numbers, the number of significant figures in the answer is equal to that of the number in the calculation with the fewest significant figures.

Lesson 5: Glossary

accuracy: A measure of how close a measurement is to the actual value of the thing being measured.

calibration: The use of a standard to ensure that measuring tools are accurate.

percent error: A measure of how far a measurement is from the actual value of the thing being measured. Percent error is calculated using this equation:

$$\% \; error = \frac{error}{actual\, value} \, x\, 100 \quad \%$$

precision: A measure of the variability of a measurement (how reproducible a measurement is). Precision is a characteristic of measuring tools and not of the thing being measured.

significant figures: The digits in a measured number that give us information about the precision of a measurement.

standard: Something with a known mass/volume/length/etc. that can be used to calibrate measuring tools.

<u>Lesson 5: Practice Sheet</u>

Significant Figures

1) Indicate the number of significant figures for each of the following measurements:

4.50 grams _____

0.45 grams _____

0.045 grams _____

0.0450 grams _____

4.5×10^3 grams _____

405 grams _____

4050 grams _____

4050. grams _____

2) What, if any, difference is there between the measurements “0.25 grams” and “0.250 grams”?

3) What is the density of a ball that has a volume of 57 mL and a mass of 121 grams?

4) If the actual density of the ball in problem 3 is 20.9 grams, what is the percent error in this measurement?

5) Why is it easier to determine the precision of a measurement than it is to determine its accuracy?

Lesson 5: Practice Sheet Answers

Significant Figures

1) Indicate the number of significant figures for each of the following measurements:

4.50 grams	**3**	4.5 x 10^3 grams	**2**
0.45 grams	**2**	405 grams	**3**
0.045 grams	**2**	4050 grams	**3**
0.0450 grams	**3**	4050. grams	**4**

How we got these numbers:

- *4.50 grams: There is a decimal point, so the zero at the right is significant.*
- *0.45 grams: There is a decimal point but zeros to the left of all digits are never significant.*
- *0.045 grams: There is a decimal point but zeros to the left of all digits are never significant.*
- *0.0450 grams: The decimal point makes the zero to the right of the 5 significant, but the zeros to the left are still not significant.*
- *4.5 x 10^3 grams: There are two significant figures, the 4 and 5.*
- *405 grams: All three digits are significant.*
- *4050 grams: The zero between the 4 and 5 is significant, but the zero after the 5 is not because no decimal is shown.*
- *4050. grams: The zero between the 4 and 5 is significant, and the last zero is also significant because a decimal is shown.*

2) What, if any, difference is there between the measurements "0.25 grams" and "0.250 grams"?
Numerically, there's no difference. However, the way that data are written tells us that "0.25 grams" is precise to the nearest 0.01 grams, while "0.250 grams" is precise to the nearest 0.001 gram.

3) What is the density of a ball that has a volume of 57 mL and a mass of 121 grams?
Density = mass / volume = 121 g / 57 mL = 2.123 g/mL. However, because the measurement "57 grams" has only two significant figures, our answer also must have two significant figures, making it 2.1 g/mL.

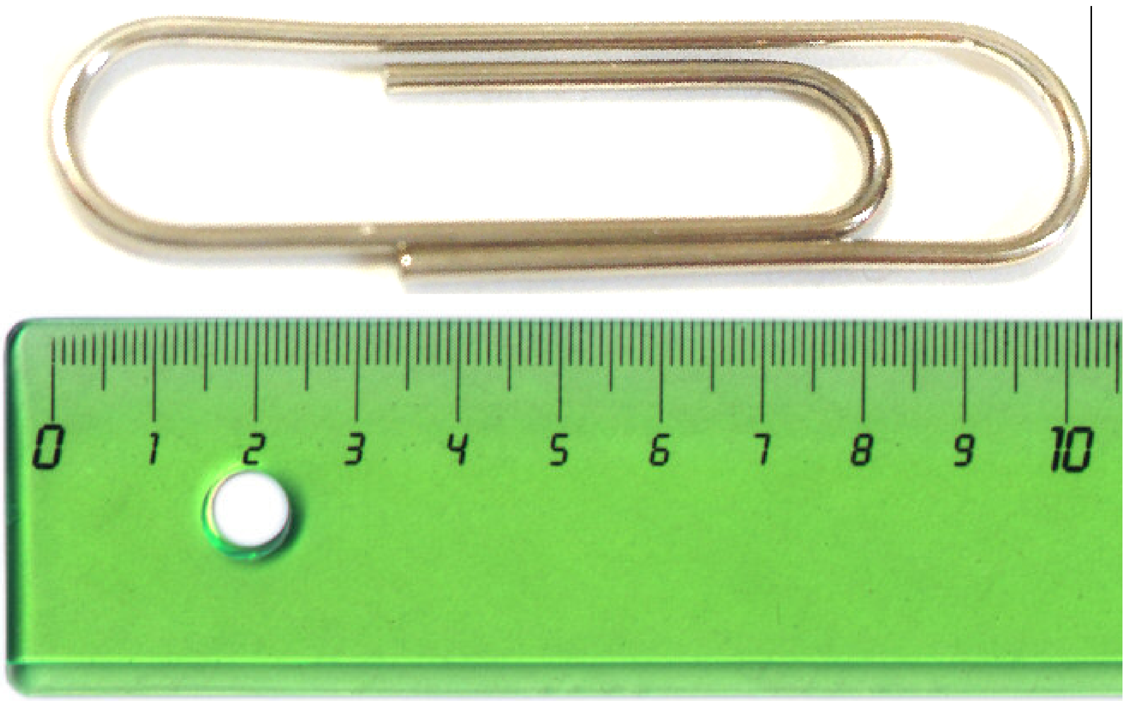
4) If the actual density of the ball in problem 3 is 20.9 grams, what is the percent error in this measurement?
0%. Though we should use the equation that percent error = (error / actual answer) x 100%, in this case the error is zero. Why? When we use significant figures, 2.1 g/mL – 20.9 g/mL rounds to 0. As a result, there is no error that we can detect with our measurement.

5) Why is it easier to determine the precision of a measurement than it is to determine its accuracy?
To determine accuracy, you must first know the actual value of the thing being measured. To determine precision, you only need to look at the number of significant figures in the measurement.

Lesson 5 Lab Activity: Making Measurements

In this lab, you will make a variety of measurements using equipment you have around the house. However, there may be slightly more to this than you previously thought. Here's a guide for how to write down measurements when you collect data.

- **Digital equipment**: If you take data using digital equipment (i.e. equipment with a computerized readout), you simply write down whatever it says. For example, if you stand on a bathroom scale and it says “163 lbs”, just write down “163 lbs.”
- **Analog equipment**: When taking data using analog equipment (i.e. equipment like a ruler, where you estimate the measurement by looking at the lines), write down as many digits as the lines directly indicate, plus one that you estimate. For example, if you have a ruler with lines that indicate “millimeters (mm)”, you would write your answer to mm *plus* one digit that you estimate.



Our estimate of the length of this paper clip would be 10.23 cm. The last digit indicates our estimate that the paper clip's length is about 3/10 the way between the 10.2 and 10.3 line.[6]

With that, let's start measuring![7]

6 *Paper clip image: By Haragayato [CC BY-SA 2.5], via Wikimedia Commons; Ruler image: By Luigi Chiesa [GFDL, CC-BY-SA-3.0, or CC BY-SA 2.0], via Wikimedia Commons.*

7 *And don't forget significant figures!*

Station 1: Measuring volume with a graduated cylinder

Use a graduated cylinder to find the following volumes. Be sure to use the proper number of significant figures in your answer!

1) What is the maximum volume of a coffee cup? _______________

2) What is the maximum volume of an empty soda can? _______________

Station 2: Measuring volume with a measuring cup

Use a measuring cup to find the following volumes. Be sure to use the proper number of significant figures in your answer!

1) What is the maximum volume of a coffee cup? _______________

2) What is the maximum volume of an empty soda can? _______________

Station 3: Measuring mass with a kitchen scale

Use a kitchen scale to find the following weights. Be sure to use the proper number of significant figures in your answer!

1) What is the mass of a can of beans? _______________

2) What is the mass of a stuffed animal? _______________

Station 4: Measuring mass with a bathroom scale

Use a bathroom scale to find the following weights. Be sure to use the proper number of significant figures in your answer!

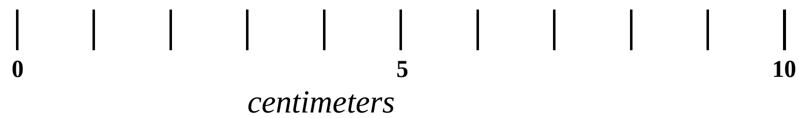
1) What is the mass of a can of beans? _______________

2) What is the mass of a stuffed animal? _______________

Station 5: Measuring distance with a ruler

Using the ruler printed below, find the following lengths. Be sure to use the proper number of significant figures in your answer!

Ruler:



1) What is the length of a sticky note? _______________

2) What is the length of a paper clip? _______________

Station 6: Measuring distance with a ruler

Using the ruler printed below, find the following lengths. Be sure to use the proper number of significant figures in your answer!

Ruler:

1) What is the length of a sticky note? _______________

2) What is the length of a paper clip? _______________

Post-lab questions:

1) In station five you recorded different lengths for the Post-It note and paper clip than you did in station six. Why is this, and what is the significance of this difference?

2) Why can't we write numbers with as many significant figures as we want? For example, if we measure something with an ordinary ruler, why is it wrong to write our measurement as "0.928772662 centimeters"? Explain.

3) If we had an accurate and precise enough instrument, is there any reason we couldn't write down a value to 15 decimal places (as in the number 0.123456789012345)? Explain.

4) In your own words, what's the difference between precision and accuracy?

5) 3" sticky notes have a width of 7.62 cm. If you measured this note in station 5 and recorded a width of 7.5 cm, what would your percent error be?

Lesson 5 Lab Answers: Making Measurements

Introductory note:

In this lab, we're not checking to see that the specific measurement of each value is correct. I think we can probably assume that kids are bright enough to use simple tools to take accurate measurements. If the answers given here are not correct, it's probably more a case of misreading the measuring tool than a lack of understanding about how to use it.

However, this *doesn't* mean that there are no incorrect answers for this lab. Though the exact values for each measurement don't really matter, what *does* matter is the precision with which each measurement has been taken. Even if these measurements are what we'd normally consider correct, the wrong number of decimal places may give us an incorrect idea about how precise our data are. This can make precise data look kind of lousy, or lousy data look precise. As a result, when you look over these answers, making sure that the number of decimal places is correct is of primary importance!

Equipment needed for this lab:

Station 1:

- A graduated cylinder (this should have been obtained during Lesson 4. If you don't have a graduated cylinder, use of a pail or blender pitcher with markings for volume may be substituted)
- A large pen cap (a marker cap is best)

Station 2:

- A measuring cup (if you didn't use a graduated cylinder in station 1, it would be best to use a measuring cup of a much different size than you did in station 1).
- The same pen cap as in station 1.

Station 3:

- One can of beans (at least 16 oz)
- One stuffed animal
- One kitchen scale

Station 4:

- The same can of beans and stuffed animal from station 3.
- One bathroom scale

Stations 5 and 6:

- One sticky note[8]
- One large paper clip

The stations in this lab are paired: Stations 1 and 2 are paired, as are 3 to 4 and 5 to 6.

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8 *Fun fact: 3M, the company that makes Post-It™ notes, asked me to submit this lab to their marketing and legal people to use the words "Post-It note" rather than "sticky note".*

Safety:

There are no safety issues in this lab and goggles are not required.

Room destruction factor:

Because the equipment used doesn't generate a mess, neither will this lab.

How the lab works:

Each pair of stations is measuring the same thing: Stations 1 and 2 measure volume, stations 3 and 4 measure mass, and stations 5 and 6 measure length. Ideally, the measurements should be the same, varying only in the number of significant figures that are appropriate for each measuring tool. As a result, most of the grading for this lab is not in the absolute value of the measurements but in the number of decimal places used to write the measurements. Make sure your child is clear on how to properly write the correct number of significant figures for a measured value before setting them loose. The first page of the lab should help with this.

What can go wrong:

Not much. As long as you have the right measuring equipment, this lab should be smooth sailing.

<u>Station 1: Measuring volume with a graduated cylinder</u>

Use a graduated cylinder to find the following volumes. Be sure to use the proper number of significant figures in your answer!

1) What is the maximum volume of a coffee cup?
A 10 mL graduated cylinder has gradations corresponding to 0.1 mL, so the answer should be given to the nearest hundredth of a mL in the format "XXX.XX mL." If a 50 or 100 mL graduated cylinder is used, the gradations correspond to 1 mL so the answer should estimate the tenths of a mL in the format "XXX.X mL"

2) What is the maximum volume of an empty soda can?
Similar to #1, the answer will be formatted XXX.XX mL if a 10 mL graduated cylinder is used, and XXX.X mL if a 50 or 100 mL graduated cylinder is used.

Station 2: Measuring volume with a measuring cup

Use a measuring cup to find the following volumes. Be sure to use the proper number of significant figures in your answer!

1) What is the maximum volume of a coffee cup?
A measuring cup may be a little more problematic than a graduated cylinder, because it wasn't designed to be used for high precision measurements. For the measuring cup in my own kitchen, the gradations are marked every 25 mL (as in 50 mL, 75 mL, etc.) so it seems reasonable to round the answer to the nearest 10 mL, giving an answer of XX0 mL (e.g. 210 mL).

2) What is the maximum volume of an empty soda can?
Similarly, the volume of a soda can should be rounded to the nearest 10 mL, giving an answer in the format XX0 mL (e.g. 370 mL).[9]

Station 3: Measuring mass with a kitchen scale

Use a kitchen scale to find the following weights. Be sure to use the proper number of significant figures in your answer!

1) What is the mass of a can of beans?
If you have a digital scale (and you probably do), just record the measurement from the display. For example, if the readout says "875 grams", just write that down.

2) What is the mass of a stuffed animal?
Again, the answer should just be whatever is directly shown on the scale display.

Station 4: Measuring mass with a bathroom scale

Use a bathroom scale to find the following weights. Be sure to use the proper number of significant figures in your answer!

1) What is the mass of a can of beans?
If your bathroom scale is electronic, just write down whatever the display says. If it has a dial on it with readings for every pound, round to the nearest 0.1 lb. For example, a can of beans may be said to weigh "1.3 lb."

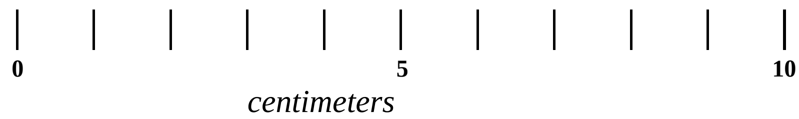
2) What is the mass of a stuffed animal?
As is the case for the previous question, if your bathroom scale is electronic, just write down whatever the display says. If it has a dial on it with readings for every pound, round to the nearest 0.1 lb.

9 *The volume of the soda in a 12 oz. soda can is about 355 mL. However, there is a small amount of space in the top that's not filled, which brings up the volume slightly.*

Station 5: Measuring distance with a ruler

Using the ruler printed below, find the following lengths. Be sure to use the proper number of significant figures in your answer!

Ruler:



1) What is the length of a sticky note?
   This ruler is precise to the nearest whole centimeter, so the answer should be rounded to the nearest tenth of a centimeter (e.g. "7.6 cm")

2) What is the length of a paper clip?
   Again, the answer should be rounded to the nearest tenth of a cm.

Station 6: Measuring distance with a ruler

Using the ruler printed below, find the following lengths. Be sure to use the proper number of significant figures in your answer!

Ruler:

1) What is the length of a sticky note?
   This ruler is precise to the nearest tenth of a centimeter, so the answer should be rounded to the nearest hundredth of a centimeter (e.g. "7.62 cm")

2) What is the length of a paper clip?
   Again, the answer should be rounded to the nearest hundredth of a cm.

Post-lab questions:

1) In station five you recorded different lengths for the sticky note and paper clip than you did in station six. Why is this, and what is the significance of this difference? Why can't we write numbers with as many significant figures as we want?
   Though the sticky note and paper clip were the same length in both stations, the measuring tool had different levels of precision from one another. As a result, our answer had to take into account the fact that both measurements had different precision by showing a different number of digits.

2) For example, if we measure something with an ordinary ruler, why is it wrong to write our measurement as “0.928772662 centimeters”? Explain.
After the first couple of digits, you're just making a guess about how long something is. If your ruler can measure 0.1 cm increments, your eyes and best judgment can allow you to tell the difference between 0.11 and 0.12 cm. However, you simply can't see differences between 0.121 and 0.122 cm using an instrument like this, so your measurement can't indicate that it does.

3) If we had an accurate and precise enough instrument, is there any reason we couldn’t write down a value to 15 decimal places (as in the number 0.123456789012345)? Explain.
If you had an instrument that could meaningfully measure that number of digits, then there's no reason you couldn't record all of them. However, it is extremely unlikely that one measuring tool would be able to measure fifteen decimal places at once.

4) In your own words, what’s the difference between precision and accuracy?
Precision measures the resolution of a measured value, which is determined by how well the measuring tool can repeatably record the same measurements. Accuracy measures whether the measured value is correctly measuring the actual value of the thing being measured.

5) 3” sticky notes have a width of 7.62 cm. If you measured this note in station 5 and recorded a width of 7.5 cm, what would your percent error be?

$$\textbf{\% error} = \frac{error}{actual\,value} x\,100 \ \ \textbf{\%}$$

In this case, it would be (0.1 cm/7.62 cm) x 100% = 1.3%. You may be wondering why we used “0.1 cm” instead of “0.12 cm” as the error, because 7.62 – 7.5 = 0.12 cm. It's because of our old friend significant figures. Recall that when adding or subtracting numbers, the answer can only be as precise as the least precise value being measured.

Lesson 5: Assessment

Questions 1-4: To find the mass of a chemical sample, I weighed it on a balance three times. The first measurement was 0.340 grams, the second was 0.341 grams, and the third was 0.338 grams.

1) Based only on these data, were these measurements precise? Why or why not.

2) Based only one these data, were these measurements accurate? Why or why not.

3) The mass of this sample can be determined by averaging the masses of the three measurements I took. Using the data from #1, find the mass of the sample.

4) It turns out that the actual weight of the sample was 0.341 grams. What was the percent error in my measurements?

5) How many significant figures are in the following measured values:

- 0.088 grams _____
- 8800 grams _____
- 8.800 grams _____
- 8.80×10^2 grams _____

6) I weigh 85 kg and the vet told me that my dog weighs 10.5 kilograms. Together, how much do my dog and I weigh?

<u>Lesson 5: Assessment</u>

Answers

Questions 1-4: To find the mass of a chemical sample, I weighed it on a balance three times. The first measurement was 0.340 grams, the second was 0.341 grams, and the third was 0.338 grams.

1) Based only on these data, were these measurements precise? Why or why not.
Because the three data are very close to one another, we can assume that the answer was fairly precise. If your child believes that the data were not very precise because they weren't identical, let him or her know that variations when taking measurements is normal when performing experiments.

2) Based only one these data, were these measurements accurate? Why or why not.
It is impossible to say if they were accurate without knowing the actual value.

3) The mass of this sample can be determined by averaging the masses of the three measurements I took. Using the data from #1, find the mass of the sample.
Averaging the three numbers gives an answer of 0.3397 grams. However, because each measurement was precise only to the thousandth of a gram, our answer must share this precision, giving it a value of 0.340 grams.

4) It turns out that the actual weight of the sample was 0.341 grams. What was the percent error in my measurements?
(0.001 gram / 0.341 gram) x 100% = 0.3% error. (The answer is rounded down to one significant figure from 0.293% because the number 0.001 gram has only one significant figure).

5) How many significant figures are in the following measured values:

- 0.088 grams **2**
(the zeros in front are not significant)
- 8.800 grams **4**
(the zeros at the end are significant because a decimal is shown)
- 8800 grams **2**
(the zeros after are not significant because no decimal is shown)
- 8.80×10^2 grams **3**
(the zero at the end is significant because a decimal is shown)

6) I weigh 85 kg and the vet told me that my dog weighs 10.5 kilograms. Together, how much do my dog and I weigh?
Adding them together gets an answer of 95.5 kg. However, since my weight is only precise to the nearest kilogram, the answer can only be precise to the nearest kilogram. As a result, we would say that, together, we weigh 96 kg.

Lesson 5: References for further study

Scientific notation
If you're not already familiar with the concept of scientific notation, you can see a simple guide and some practice problems over at https://www.mathsisfun.com/numbers/scientific-notation.html.

How to use different bits of scientific equipment
If you're not already familiar with taking measurements, you may want to have a look at the following:

- How to read graduated cylinders: http://www2.ohlone.edu/people/jklent/labs/gradcyl.pdf
- How to read a thermometer: http://brooksidepress.org/vitalsigns/lessons/lesson-2-temperature/2-0-8-how-do-i-read-a-glass-thermometer/
- How to read a ruler: https://www.chemteam.info/SigFigs/Measuring.html

Significant figures:
If you prefer to learn significant figures via video, here's a good one that will tell you what they are, how to find them, and what they mean:
https://www.youtube.com/watch?v=b38hFWvEjwI

Error:
For more information about accuracy, precision, sources of error, and significant figures, visit:
http://www.ece.rochester.edu/courses/ECE111/error_uncertainty.pdf

Two stories about why significant figures are important:

- http://www.chemteam.info/SigFigs/SigFigsFable.html
- http://chemistry-reference.com/sd/default.asp