How Certain Are You About That Measurement?

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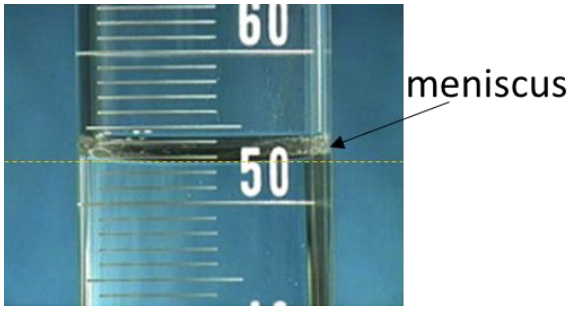
16 minutes for this section

Model 1: Correctly reporting the volume of water in a graduated cylinder.
A student wants to correctly measure the volume of a quarter cup in milliliters. This student fills a quarter cup with water and pours it into the graduated cylinder shown in the model.



Key Questions:

1. Examine the graduated cylinder carefully. What is the volume difference between the *closest* spaced increments (or ticks) in mL?

   1 mL

2. The student wisely states that they are certain the volume is greater than 52 mL but less than 53 mL. Based on the measuring device (the graduated cylinder), why can this statement be made? Note: Reading is always made at the bottom of the meniscus.

   Because the meniscus is between the two lines of 52 mL and 53 mL

3. Since the student knows for certain that the volume is between 52 mL and 53 mL, they estimate a volume of 52.7 mL. Why would you say this is a good estimate for the volume?

   Because the meniscus is about 3/4 of the way up to the 53 mL mark

4. This student asks a good friend to measure the volume of the liquid, and this person measures a volume of 52.8 mL. Would you say that this is *also* a good estimate? Yes
   Why or why not?
   You cant be exact with the tenths place of the measurement, so you have to approximate it and it's really close to the 53 mL mark but not quite there

Every measurement contains known/certain digits and **one** estimated digit. The known (or certain digits) should remain the same regardless of who makes the measurement, whereas the estimated digit has some variability since it must be estimated. There is always **one** estimated digit (the last one) in any measurement.

5. The two measurements made above are shown below. Circle the certain digits and underline the estimated for each measurement.

   52.7 mL 52.8 mL

6. The student asks a few other friends to make measurements of the quarter cup. The measurements were reported as 52.6 mL, 52.7 mL, and 52.9 mL.
    a. Comment on how well these measured values agree with each other.

They agree well because only the estimated digit is changing. And its within 0.3 of each other

Commonly, there is some disagreement in the measured values which often arise from the person making the measurement. Precision refers to the degree of agreement among several measurements (reproducibility).

    b. Are these measurements precise? Yes Explain.

All the measurements are within 0.3 of each other, I would say that's pretty precise since its the estimated digit

7. The student decides to Google the actual volume of a quarter cup in milliliters. The actual value is 59.15 mL.
    a. Comment on how well the measured values above agree with the actual value.

They do not agree, one of the certain digits is not the same and is off by a lot

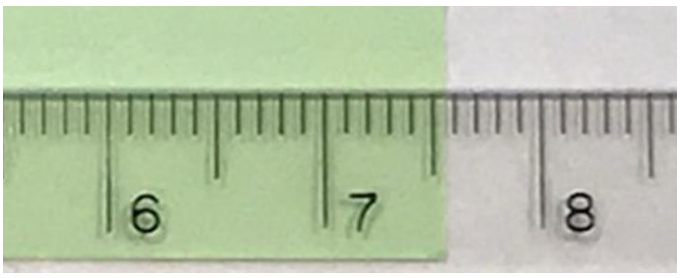
Accuracy refers to the agreement of a particular value (or average of values) with a true or actual value.

    b. Are these measurements accurate? No Explain.

The certain digits are different and far off from the actual value

Exercises:

8. The length of a piece of paper needs to be measured. The ruler measures in centimeters.



    a. One student makes a measurement of 7.57 cm and the other a measurement of 7.572 cm. Which of the two measurements was made correctly? The first Explain your answer.

The second has too many digits, the ruler doesn't have that kind of accuracy

    b. The actual length of the piece of paper is 7.60 cm. Is the measurement made by the first student accurate? Yes Explain your answer.

If you round the estimated digit, it becomes 7.60 making it accurate

Entire class discussion:

Method development:

Items needed for *each* member of the group: ruler, cube, wooden sphere, teal scoop, and 10 mL graduated cylinder.

9. Examine the ruler and the 10 mL graduated cylinder. In which place is the estimated digit for each measuring device?
    a. Ruler (in cm) hundredths
    b. 10 mL graduated cylinder hundredths
10. Examine the cube. Describe a way to determine its volume using the items provided. You need to indicate the measuring device you will use. No measurement or calculation performed at this point.

    Using the ruler, you can measure the length, width, and height of the cube and multiply them all together. Since its a cube you can just cube one of the sides and it should be the same
11. Examine the wooden sphere. Describe a way to determine its volume with the items provided. In your description, indicate the measuring device you will use. No measurement or calculation performed at this point.

    You can place the sphere over the ruler to measure the diameter, half that to get the radius, cube it, then multiply by 4pi/3
12. Examine the teal scoop. Describe a way to determine the volume of the scoop with the items provided. In your description, indicate the measuring device you will use. No measurement or calculation performed at this point.

    Fill the scoop with water and the pour it into the graduated cylinder. The reading on the graduated cylinder will be the volume

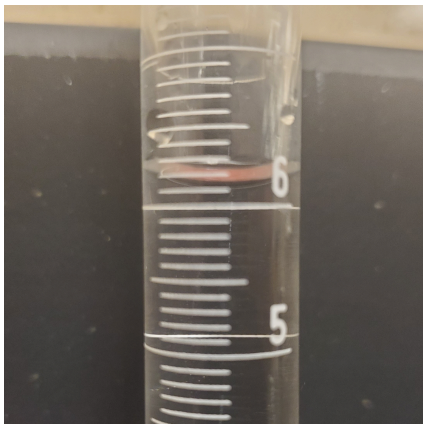
Individual data collection (each person in the group will acquire their own data):

13. Make a length measurement of the cube in centimeters using the appropriate number of significant figures with one estimated digit. With your cell phone, take a picture of this measurement (zoom in to clearly see between the increments). Your measurement will come from this picture.

    Length 2.50 cm

14. Determine the diameter of the wooden sphere in centimeters using the appropriate number of significant figures with one estimated digit. No picture is necessary for this measurement.

Length 2.90 cm



15. Determine the volume of the scoop in milliliters (tap water will be the liquid) using the appropriate number of significant figures with one estimated digit. With your cell phone, take a picture of this measurement (zoom in to clearly see between the increments). Your measurement will come from this picture.

    Volume 6.15 mL = 6.15 cm^3

Compilation of group data and group analysis:

16. In which place is the estimated digit for each measurement made above?
    a. Cube Hundredths
    b. Wooden sphere Hundredths
    c. Teal scoop Hundredths
17. Determine the mass of the cube in grams using the balance (record the mass for each group member). 1.305, 1.339, 1.224, 1.364. For a digitally reported measurement like this one, the last reported digit of the measured number is always the estimated digit. In which place is the estimated digit?
    Thousandths

18. In the table below, input the volume measurement of the scoop for each group member (including your own) and calculate an average.

	Volume of scoop (mL)
Group member	6.15
Group member	5.65
Group member	5.90
Group member	5.56
AVERAGE VOLUME	5.82

19. Are the measurements made by your group members precise? No
    a. Explain how you made this determination.

       the certain digits range by a lot, even the next certain digit to the left is different
    b. If the measurements aren't precise, suggest a reason.

       When you put water in the scoop, it can be a little higher than the actual scoop so the difference could mean why they weren't so precise

Information: Rules for counting significant figures

Nonzero integers always count as significant figures.

Example: 453.4 cm has 4 significant figures

Leading zeros are never significant.

Example: 0.00498 g has 3 significant figures

Captive zeros are always significant.

Example: 10058 has 5 significant figures

Trailing zeros are sometimes significant.

Example: 40 g has 1 significant figure; 40. g has 2 significant figures; 40.0 g has 3 significant figures.

Exact numbers have infinite significant figures.

Example: Counting numbers such as how many items in one dozen (12 would be considered to have infinite significant figures since you counted them) or the number of people in your group.

Example: Numbers by definition such as how many centimeters in one meter (100 centimeters would be exact be definition).

Exercises: Below are correctly reported measurements. Indicate the number of significant figures.

Measurement	**Significant figures**
14.55 mL	4
300 pounds	1
0.00012 grams	2
12.00 cm	4
π	infinite

Information: The rules for significant figures in mathematical operations

Multiplication or division: The number of significant figures in the result is the same as the number in the calculation that has the fewest significant figures.

Example: 0.281 m × 3.1 m

The result has two significant figures since the first number has three significant figures and the second number has two. **Answer = 0.87 m^2**

Addition or subtraction: The result has the same number of decimal places as the least precise measurement.

Example: 8.428 cm + 3.4 cm

The result goes to the tenths place since the first number goes to the thousandths place and the second number to the tenths place. The measurement, 3.4 cm, has lower precision. **Answer = 11.8 cm**

Mixed operations: Follow order of operations rules and track significant figures through each operation stepwise.

Example: (5.981 g – 5.24 g)/1.25 mL

Step 1: The first operation is subtraction (5.981 g -5.24 g). The number, 5.981, goes to the thousandths place, and 5.42 goes to the hundredths place. The result of the subtraction, therefore, goes to the hundredths place.
Answer: 0.74 g.
Step 2: The next operation is to divide 0.74 g (from previous calculation) by 1.25 mL. The number, 0.74, has two significant figures, and 1.25 has three significant figures. The result of this division, therefore, will have two significant figures.
Final Answer = 0.59 g/mL.

Exercises: Evaluate each of the following and write the answer with the correct number of significant figures. The last two problems are mixed operation calculations. Make sure that you follow order of operations and track significant figures through each operation stepwise.

20. 1012.8 cm + 90.182 cm – 6.485 cm

    1096.5

21. (55.32 in × 4.31 in)/12 in

    20

22. (4.35 × 10.0/7.1) + 13.76

    19.9

23. 16.2 × (43.6 + 0.6)

    716

Ask the teacher or lab assistant to check your work for the calculations above before proceeding.

Method development:

Items needed for *each* member of the group: 50 mL beaker, 50 mL graduated cylinder, and 10 mL graduated cylinder.

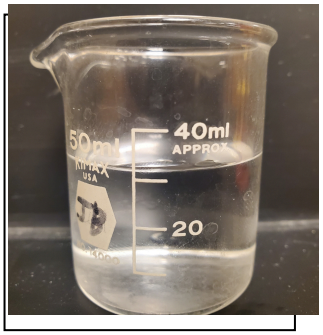
24. Examine the 50 mL beaker, the 50 mL graduated cylinder, and the 10 mL graduated cylinder. In which place is the estimated digit for each measuring device?
    a. 50 mL beaker Ones
    b. 50 mL graduated cylinder Tenths
    c. 10 mL graduated cylinder Hundredths
25. If you summed up the volumes from each of the measuring devices above, in which place would you *always* have the estimated digit? Ones Explain your answer.

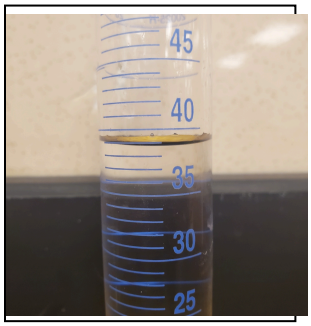
When adding/subtracting, your answer should be to same last digits place of the one that's least exact

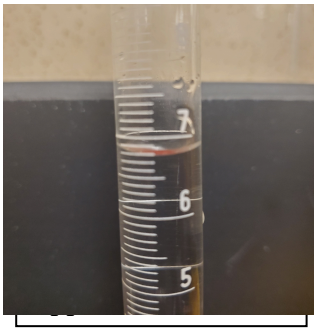
26. Let's try one. The 50 mL beaker contains 8 mL, the 50 mL graduated cylinder contains 12.3 mL, and the 10 mL graduated cylinder contains 7.86 mL. What is the sum of the volumes? 38 How many significant figures are in the sum? 2

Individual data collection (each person in the group will acquire their own data):

27. Fill each of the measuring devices between ¼ and ¾ full of water. Correctly determine the volume in each measuring device. With your cell phone, take a picture of the volume in each measurement device (zoom in to clearly see between the increments). Your measurements will come from these pictures. After acquiring a volume measurement from each device determine the sum.







Volume in 50 mL beaker	31
Volume in 50 mL graduated cylinder	38.9
Volume in 10 mL graduated cylinder	6.79
SUM OF VOLUMES	77

Compilation of group data and group analysis:

28. Each group member needs to determine the volume of the wooden sphere with their measurement made previously. Show the calculation for your volume. Make sure to report your answer with the correct number of significant figures. Each value will then be placed in the table below. Calculate an average for your group.

$$Volume_{sphere} = \frac{4}{3}\pi r^3$$

$d = 2.90$ $\quad 1.45^3 = 3.05$

$r = \frac{2.90}{2} = 1.45$ $\quad 3.05 \cdot \pi = 9.58$ $\quad 9.58 \cdot \frac{4}{3} = 12.8$ $\quad V = 12.8cm^3$

	Volume of wooden sphere (cm^3)
Group member	12.8

Group member	13.7
Group member	12.8
Group member	12.8
AVERAGE VOLUME	13.0

29. Each group member needs to determine the volume of the cube with their measurement made previously. Show the calculation for your volume. Make sure to report your answer with the correct number of significant figures. Each value will then be placed in the table below. Calculate an average for your group.

$2.50^3 = 2.50 \cdot 2.50 \cdot 2.50 = 15.6cm^3$

	Volume of cube (cm^3)
Group member	15.6
Group member	16.0
Group member	15.6
Group member	15.6
AVERAGE VOLUME	15.7

30. Are these measurements determined by your group members precise? Yes
    a. Explain how you made this determination.

    3 of them were exactly the same, the other was pretty close still

    b. If the measurements aren't precise, suggest a reason.

31. Using your measuring device, determine the volume of the cube in *inches*? 0.91 in^3 Which system of measurement was easier to take the measurement (English or metric)? Metric Explain why?

    To make it a decimal instead of a fraction was way easier for metric instead of figuring out the correct significant figure for 31/32 inches

32. The actual volume of the teal scoop is 1 teaspoon which is 4.929 mL. Is the average volume for the group accurate? No Explain how you made this determination.

    The certain digits aren't even close

33. Percent error is a numerical method to check for accuracy. Using the actual volume of the scoop, calculate the percent error in the average volume measurement from your group. Careful, this is a mixed operation calculation. Show your work.

$$percent\ error = \frac{your\ value - actual\ value}{actual\ value} \times 100.0\%$$

$5.82 - 4.929 = 0.89$ $\quad \frac{0.89}{4.929} = 0.18$ $\quad 0.18 \cdot 100.0\% = 18\%$

Ask the teacher or lab assistant to check your work for the calculations above before proceeding.

Class data: In the class data sheet (link in Canvas), input the average value for the volume of the cube and the average value for the volume of the scoop.

Method development:

Items needed for *each* member of the group: glass thermometer and 50 mL beaker.

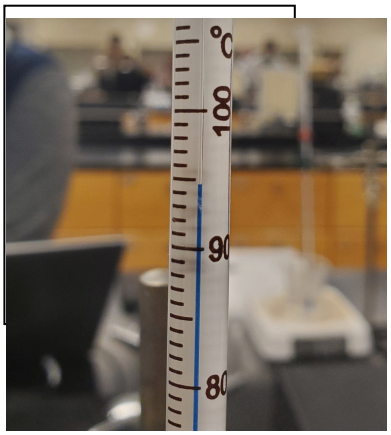
34. Examine the provided thermometer. In which place is the estimated digit? Tenths
    Report the temperature of the room with the glass thermometer. 19.5
35. Explain a method to determine the temperature of boiling water.

    Boil the water then put the thermometer in when it starts to boil

36. What do you think the temperature will be of the boiling water? 100

Individual data collection (each person in the group will acquire their own data):

37. Correctly determine the temperature in Celsius of boiling water with the provided thermometer. Each group member will boil their own water. With your cell phone, take a picture of this measurement (zoom in to clearly see between the increments). Your measurement will come from this picture.
    Boiling water temperature in Celsius: 94.9



Compilation of group data and group analysis:

38. Place the temperature of boiling water from each group member in the provided table and calculate an average temperature.

	Temperature of boiling water
Group member 1	94.9

Group member 2	88.9
Group member 3	94.8
Group member 4	92.9
AVERAGE	92.9

39. Are these measurements precise? No

a. Explain how you made this determination.

The certain digits ranged quite a bit

b. If the measurements aren't precise, suggest a reason.

It could be the amount of water, depth of the thermometer, or duration the water was boiling before measuring

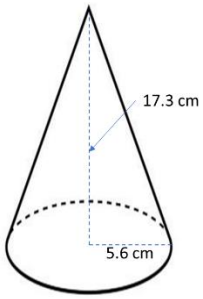
Class data: In the class data sheet (link in Canvas), input the average value for the temperature of boiling water.

Make sure all items are clean and return them to the drawer or bench. Finish cleaning any glassware used by rinsing with distilled water. Before you leave, ask the teacher or lab assistant to examine your data and laboratory space. Note: Your data must be entered into the spreadsheet before you leave.

Application of principles (to be completed individually):

40. Determine the volume of the cone. Report your answer with the correct number of significant figures.

$$Volume_{cone} = \frac{1}{3}\pi r^2 h$$



570 cm^3

41. Make a correct length measurement in centimeters for the line on each ruler.

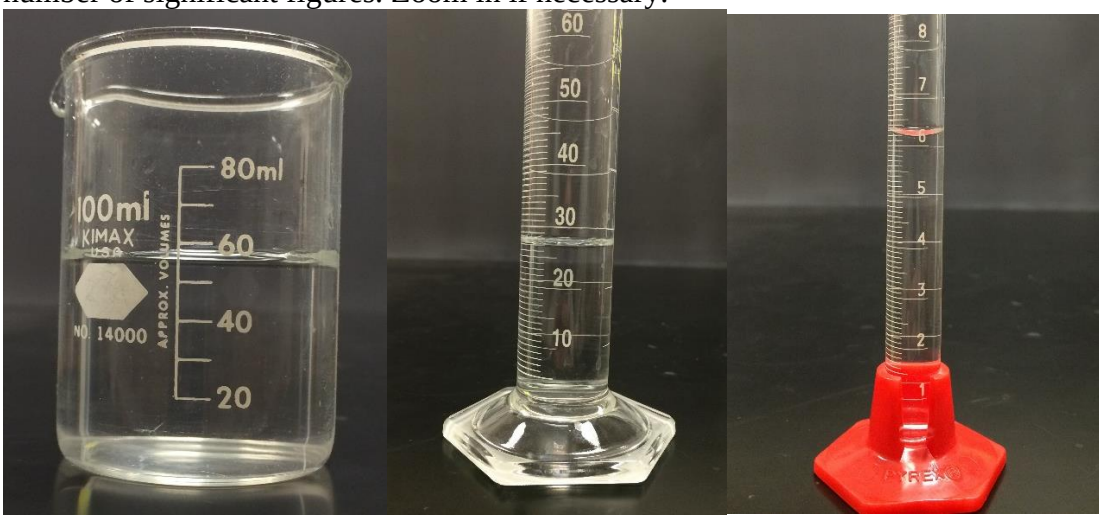
22 cm

22.5 cm

Why did the two measurements have a different number of significant figures?

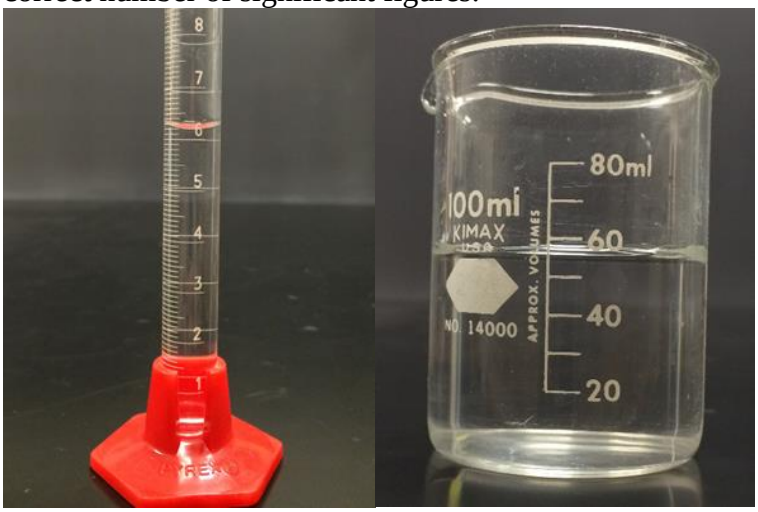
The first has marks at each ten so you can only guess for the ones. The other has marks at each one so you can guess for the tenths place.

42. What is the volume of water in each container. Report your answer with the correct number of significant figures. Zoom in if necessary.



55 mL 27.0 mL 6.15 mL

43. The water from the 10 mL graduated cylinder on the left is added to the water in the 100 mL beaker on the right. What is the total volume of water? Report your answer with the correct number of significant figures.



61 mL

44. There was probably low precision among the measurements made by your group for the volume of the wooden sphere. Explain the primary reason for this.

It was harder to measure the diameter because it depended on the angle at which you were looking at it

45. Compare your individual values (not group values) with the average values of the class in the *Class Data Sheet*. Make sure the *Class Data Sheet* is complete before doing this. You will have to wait until the end of the lab period. Fill in the following table below.

	Your individual value	**Average value of class**
Volume of cube	15.6 cm^3	15.5 cm^3
Volume of teal scoop	6.15 mL	5.36 mL
Temperature of boiling water	94.9 degrees C	94.2 degrees C

The accuracy between a measured value and an accepted value can be analyzed by performing a percent error calculation. For this calculation, the measured value is your individual value, and the accepted value will be the class average (in Google Sheet).

$$Percent\ Error = \frac{(measured\ value - accepted\ value)}{accepted\ value} \times 100.0\%$$

a. Calculate a percent error for each of your individual values. Remember, this is a mixed operation calculation.

	Percent error
Volume of cube	0.645 %
Volume of teaspoon	14.7 %
Temperature of boiling water	0.743 %

b. For each percent error greater than 5% (or less than -5%), suggest at least one source of error for your individual value being significantly different than the accepted value.

When I filled the scoop, I believe I left the dome of water over the scoop instead of making it even with the scoop while I'm guessing most other people didn't