

Scientific Inquiry and Modeling
Metric Measurement and Quantitative Data

CONCEPT EXPLORATION

Interpreting results from scientific experiments is a fundamental part of the process of science. If the data obtained from experiments is limited to qualitative observations, the interpretations will vary from person to person.

For example, while looking at a test tube containing the liquid results from an experiment, you might say the color is blue, while another person might say the color is turquoise. A colorblind person would be unable to determine the color at all.

Quantitative observations provide objective information that can be compared consistently from one person to another. For this reason, quantitative data is the **preferred type** of evidence in scientific experiments.

However, even quantitative data can have **errors** that need to be taken into consideration. You will investigate sources of measurement error in the following activities.

Engagement Activity

1. Write one qualitative observation about your teacher's desk, and one estimated quantitative observation about your teacher's desk.

The Challenge

Using the ruler and book at your desk, you will determine the volume of the book in cubic centimeters (cm^3). Indicate the possible sources of error in measurement and calculation.

Your Ideas about the Challenge

2. What will you actually measure on the book? Describe the measurements you will make.

3. How will you calculate the volume of the book using the measurements you have made?

The precision of a measurement refers to its specificity or narrowness. For example, a measurement of 4.5 cm is more precise than a measurement of 5 cm. Does the ruler allow you to measure only to the whole cm, $\frac{1}{10}$ (0.1) of a cm, or $\frac{1}{100}$ (0.01) of a cm?

4. What is the most precise measurement you can make with the ruler? In other words, what is the smallest increment marked on your ruler?

5. What is the smallest fraction of the marked increments on your ruler that you would have confidence in ($\frac{1}{10}$, $\frac{1}{100}$, etc.)?

6. What are some possible sources of error in your measurements and calculations?

At each lab station you with the following materials:
A ruler, a graduated cylinder, water, a meter stick, and a book

The Investigation

a. Using the ruler measure each of the three dimensions of the book. Record each of these measurements in the data section that follows.
b. Calculate the volume of the book. Record your calculations in the data section that follows. Be sure to show all of your calculations. Label each quantity with the appropriate units.
c. Ask two of the other members of your lab group for their calculated volumes and record those values in the data section. It is okay if those values do not agree with yours.

Data

Length (cm)	Width (cm)	Height (cm)	My calculated Book Volume (cm^3)	Lab Group Member 2 Book Volume (cm^3)	Lab Group Member 2 Book Volume (cm^3)

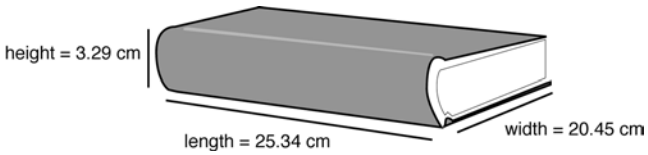
7. Did your calculated volume agree precisely with the other members of your lab group? Did it agree precisely with everyone in the class?

8. Why do you think every student did not obtain precisely the same value?

Check your work with your teacher. ☐

When you calculated the volume of the book, your calculator may have displayed many more digits than the measurements you made with the ruler. Here is an example:

Look at the level of precision of the calculated answer. This answer implies that you know the volume of the book to a precision of $\frac{1}{100{,}000}$ of a cm^3!



3.29 cm x 25.34 cm x 20.45 cm =volume = 1704.88787 cm^3

9. Is this reasonable? What was your most precise measurement? To what decimal place were you confident in making a measurement (0.1, 0.01, 0.001 etc.)?

The rule that we will use when making calculations, in this course, is that **a calculated value must be rounded to the level of precision of the least precise measurement.** Using this rule, the volume of the book illustrated above should be reported as:

volume = 3.29 cm x 25.34 cm x 20.45 cm = 1704.89 cm^3
(measurement error = ±0.01 cm^3)

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10. Evaluate the following student statement about the investigation you performed. Identify ideas that are consistent with your observations and others that are not consistent with your observations.

"I used one of our cheap plastic rulers with millimeter markings to find the volume of a sugar cube in cm^3. I measured the length to be 1.55 cm, the width to be 1.5 cm, and the height to be 1.49 cm. I calculated the volume to be 3.46425 cm^3. I am very confident in my calculation of the volume to the last decimal point."

Rules of the Road

Inconsistencies in measurement technique and calculations can make it difficult for scientists to share data in a meaningful way. There are a few rules you need to be familiar with.

Measurement

When using a measuring device like a ruler, meter stick, or triple beam balance, it is possible to estimate a value between the finest marks on the measurement scale.

The diagram on the right illustrates this estimation process with a ruler and a bumblebee.

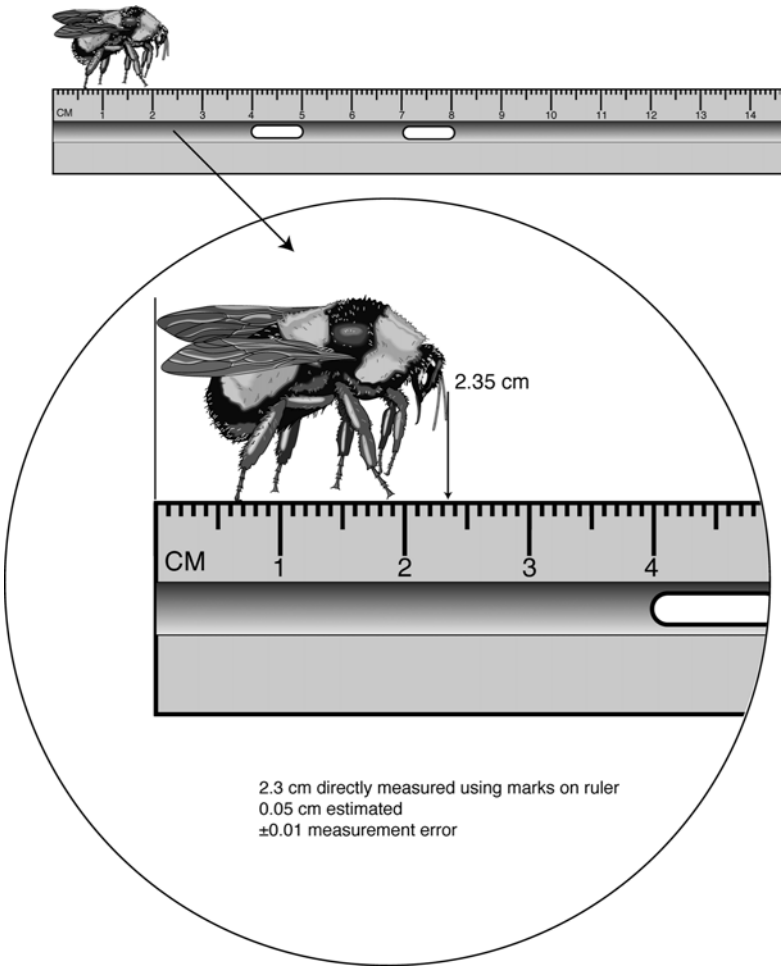
In this example, the person making the measurement is required to estimate to the $\frac{1}{100}$ (0.01) centimeter value.

Given that this final digit is estimated, there is some uncertainty associated with it. The actual value may be slightly above or below the estimate.

This uncertainty is referred to as **measurement error**.

Measurement error is defined by a plus or minus (±) value. The most commonly applied rule is that the measurement error is ±1 above or below the estimated value.

Using this rule, the length of the bumblebee is 2.35 cm ±0.01 cm.



11. Measure the length of a pencil to the greatest possible precision with the ruler, and indicate the measurement error associated with the observation.

It is important to note that some measurement devices provide digital values (like a stopwatch or electronic balance). It is not possible to estimate values with a digital display of this kind.

When using a device with a digital display, the measurement error is ±1 of the last displayed digit. The balance on the right displays a mass of 233.3g. The measurement error associated with this is balance is ±0.1g.



12. What is the largest possible mass this basketball could have? What is the smallest?

Measurement Technique - Linear Measurement

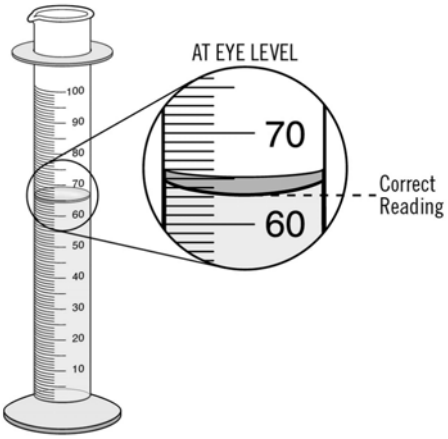
Measurement errors can be made if the correct technique is not used to make the measurement. You must make sure to position yourself so that you are looking directly (perpendicular) to the scale where the measurement is made. The diagram below illustrates the error that can be introduced when the correct technique is not used.

13. Measure the height of an object when looking down from above as the diagram illustrates, and then from straight on. Write the name of the object and the two measurements in the space below. Indicate which measurement was made when you were using the correct technique.



Measurement Technique - Measurement of Liquid Volume

Water will adhere to the walls of a container that holds it. As a result, the surface of the water within the container is not perfectly flat. The water sticking to the walls of the container will cling to a position slightly above the majority of the surface of the water. This inverted-bubble shape is called a **meniscus.** The most accurate measurement of the volume is made when you read the volume indicated at the **base** of the meniscus.



14. Put any volume of water in a graduated cylinder. Read the volume of water from the base of the meniscus, and from the highest point the water reaches within the cylinder. Record both of these values in the space below. Indicate which reading is the correct reading of the volume.

Check your work with your teacher.

CONCEPT DEVELOPMENT

Scientists develop and use models to describe the natural world. The quality of these models is related to the precision with which they can be used to predict the behavior of the system being modeled. Quantitative data can be used in supporting or rejecting scientific models. The quality of quantitative data is a critical concern of scientists.

In the concept exploration of this lesson you examined experimental errors that were related to making quantitative measurements. This error is referred to as **measurement error**. In this activity, we will examine **random error**.

Scientists repeat experiments to test the predictive ability of models, and to test the conclusions of other experiments. When an experiment is repeated, there are always small variations in the experimental set up that reduce the chances that exactly the same results are obtained with each trial.

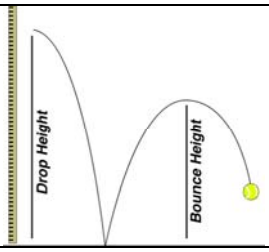
Engagement Question

1. Can you throw a die in such a way that you could obtain the same result every time? What would you do to try to get the same result every time?



The Challenge

You will collect data from observations made of the bounce height of a ball after the ball is dropped from a constant height.



Your Ideas about the Challenge

2. What potential problems will you face in reproducing the experiment as consistently as possible? List at least two.

3. What potential problems will you face in measuring the bounce height? List at least two.

4. What could you do to release the ball from rest, and from the same height every time?

5. What will you do to accurately measure the height of the first bounce?

At each lab station you will find the following materials:
a tennis-ball and 2 meter sticks.

The Investigation

a. Hold the meters sticks vertically so that you can measure both the drop and the bounce height.
b. Drop the ball from a height of 1.5 meters (150 cm) and measure the height of the bounce as precisely as possible. Repeat the experiment for 10 trials. Record your observed bounce heights in the data tables that follow. Be sure to label all of the heights with the appropriate units.

Data

Drop Height (cm)	Trial 1 Bounce Height	Trial 2 Bounce Height	Trial 3 Bounce Height	Trial 4 Bounce Height	Trial 5 Bounce Height
150					

Drop Height (cm)	Trial 6 Bounce Height	Trial 7 Bounce Height	Trial 8 Bounce Height	Trial 9 Bounce Height	Trial 10 Bounce Height
150					

6. Examine the data. Did you observe exactly the same height for every single trial?

7. To what level of precision can you fairly measure the height of the bounce (0.1 mm, 1 mm, 1 cm, or 1 m)?

8. What bounce heights appeared most frequently?

9. If you had to determine a height that would be the most representative height (it doesn't have to be a data point), what would it be and how would you determine it?

10. If the results from the trials were spread far apart (20 cm apart) as opposed to very close together (2 cm apart) would you say that the experimental set up was consistent from trial to trial, or inconsistent?

Check your work with your teacher.

You just observed in the last investigation that despite your best efforts to conduct experiments in a consistent manner, small variations in your set up yielded a range of data values. How do determine a value that is representative of your experiment? There are at least three different ways of expressing representative values.

The **average** or **mean** value can be used as the most representative value for a given set of data. The average or mean value is determined using the following expression:

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$$\text{Mean Value } (\bar{x}) = \frac{\text{Sum of Values}}{\text{Number of Values}}$$

Here are some sample data values: $2.0,\ 3.0,\ 4.0,\ 3.0,\ 5.0,\ 1.0,\ 2.0,\ 3.0$

$$\text{Mean Value } (\bar{x}) = 2.9 = \frac{\text{Sum of Values} = 23}{\text{Number of Values} = 8}$$

11. Calculate the mean value for the observations you made with your bouncing ball. Show all of your calculations and be sure to label the mean value with the appropriate units.

This value is not necessarily the most common value. The value that occurs most frequently is called the **mode**.

12. What was the mode for your observed data? If you didn't have a mode, explain why not.

Another representative value that can be used to express a conclusion is the median. The **median** is the value that is in the middle of your data. You would have to arrange your data from the lowest to the highest value and then determine which value was in the middle of your data. In this case, since you had 10 observations you would have two values that were in the middle. These would be the 5th and 6th values in order.

13. Arrange the data that you received from the lowest value to the highest value in the table you see below.

1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th

14. Record the 5th and 6th values that you received and then take the average between these two values. This is the median value of your data.

15. Evaluate the following student statements. Identify parts of the statements that are consistent with your observations and others that are not consistent with your observations.

Student A

"Quantitative data allows a scientist to objectively compare results and make precise predictions with models. There is measurement error that limits your ability to precisely measure an event, and random error that limits your ability to obtain identical results over and over."

Student B

"Quantitative data is the best kind of data to use in any experiment. You can measure anything as specifically as you want, and you'll always get exactly the same results if you repeat the same experiment over and over."

Check your work with your teacher.

CONCEPT REFINEMENT

Review

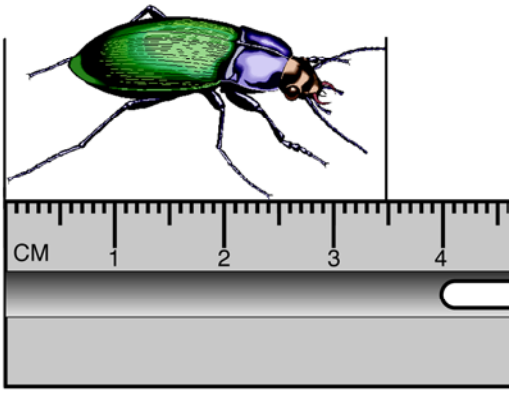
We have investigated some of the fundamental concerns about collecting high-quality quantitative data. There is uncertainty associated with the precision of any measuring device. We call this uncertainty **measurement error**, and have defined specific rules to describe the amount of error that may exist for a given measurement.

We have also examined how variations in the way an experiment is performed can yield a range of results. The uncertainty due to these variations is called **random error**.

The following sections will describe quantitative measurements made by students. It will be your job to evaluate their measurements and describe the strengths and weaknesses of their efforts.

Billy catches the beetle illustrated on the right, and measures its length before releasing it.

He measures its length to be 3.5 cm ±0.1 cm.



1. Is this measurement as precise as possible given the scale of the ruler?

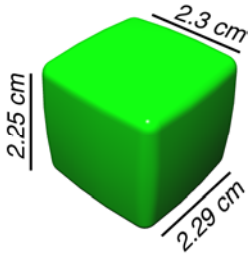
2. What is the most precise length for the beetle you could measure with this ruler?

3. What is the measurement error associated with this ruler?

Check your work with your teacher.

Sharon is trying to determine the volume of a block of clay. She accurately makes the measurements illustrated on the right.

She calculates the volume to be 11.85075 cm^3 ± 0.00001 cm^3.



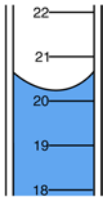
4. Is this measurement reasonable given the precision of the individual measurements? Why or why not?

5. What is the most precise value for the calculated volume of the block of clay given these measurements?

6. What is the most appropriate measurement-error value for the calculated volume of this block of clay?

Check your work with your teacher.

Tonya is measuring a specific volume of water with a graduated cylinder. She measures the volume to be 20.6 ml ±0.1ml.



7. Is this measurement as precise as possible given the scale of the graduated cylinder?

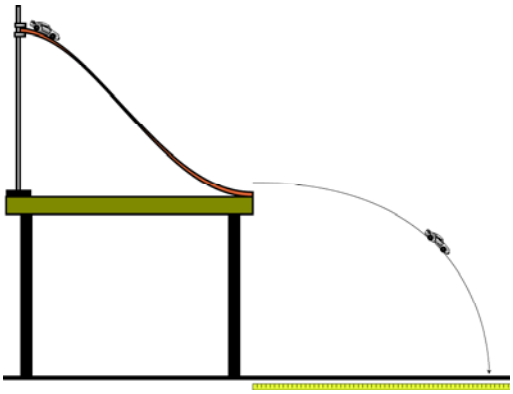
8. What did Tanya fail to consider when she made this measurement? What should she have done differently?

9. What would be a better interpretation for the volume of water contained in this cylinder?

Check your work with your teacher.

Lynn places a toy car on the top of a flexible track and allows it to race down the hill and shoot off onto the floor. She notices that it hits about the same spot every time. She uses a meter stick to measure exactly where it lands. She releases the car from about the same spot 20 times. Her data is shown below.

75 cm, 70 cm, 77 cm, 75 cm, 71 cm, 77cm, 74 cm, 74 cm, 75 cm, 76 cm, 72 cm, 72 cm, 76 cm, 78 cm, 71 cm, 76 cm, 75 cm, 75 cm, 74 cm, 76 cm



10. Why isn't the exact same flight distance observed for every single trial?

11. What is the mean for the flight distance? Be sure to show your calculations.

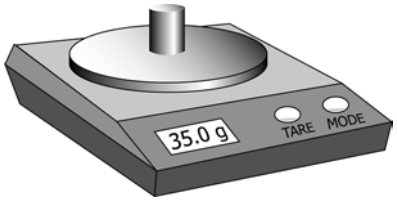
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12. What is the mode for the flight distance? Explain how your determined this value.

13. What is the median value for the flight distance? Explain how you arrived at this value.

Check your work with your teacher.

Darren uses an electronic balance to measure the mass of a small metal cylinder. The balance displays a mass of 35.0 g. Darren records this mass and indicates that there is no error because the balance is electronic, and there is no need to estimate any values.



14. Is Darren's understanding correct? Why or why not?

Check your work with your teacher.

Tina's teacher has challenged her class to find out how many jelly beans are in a jar at the front of the room. The teacher informs the class that the jar contains six-50ml scoops of beans.

Tina is determined to figure out how many beans are in the jar. She counts how many beans are present in several 50 ml scoops. She notices that the number of beans in a single scoop is not always exactly the same, so she decides to conduct many trials. Her data is shown below.



Trial Number	Number of Beans in 50 ml	Trial Number	Number of Beans in 50 ml	Trial Number	Number of Beans in 50 ml	Trial Number	Number of Beans in 50 ml
1	67	6	68	11	68	16	62
2	62	7	69	12	70	17	66
3	63	8	70	13	73	18	67
4	65	9	65	14	72	19	64
5	66	10	66	15	68	20	70

15. Using Tina's data, predict how many jelly beans are in the jar at the front of the room. Explain in detail how you arrived at your prediction.

Check your work with your teacher.

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