Pearson

E.3: The Reliability of a Measurement

The reliability of a measurement depends on the instrument used to make the measurement. For example, a bathroom scale can reliably differentiate between 65 lb and 75 lb but probably can't differentiate between 1.65 and 1.75 lb. A more precise scale, such as the one a butcher uses to weigh meat, can differentiate between 1.65 and 1.75 lb. The butcher shop scale is more precise than the bathroom scale. We must consider the reliability of measurements when reporting and manipulating them.

Reporting Measurements to Reflect Certainty

Scientists normally report measured quantities so that the number of reported digits reflects the certainty in the measurement: more digits, more certainty; fewer digits, less certainty.

For example, cosmologists report the age of the universe as 13.7 billion years. Measured values like this are usually written so that the uncertainty is in the last reported digit. (We assume the uncertainty to be ± 1 in the last digit unless otherwise indicated.) By reporting the age of the universe as 13.7 billion years, cosmologists mean that the uncertainty in the measurement is ± 0.1 billion years (or ± 100 million years). If the measurement was less certain, then the age would be reported differently. For example, reporting the age as 14 billion years would indicate that the uncertainty is ± 1 billion years. In general,

Scientific measurements are reported so that every digit is certain except the last, which is estimated.

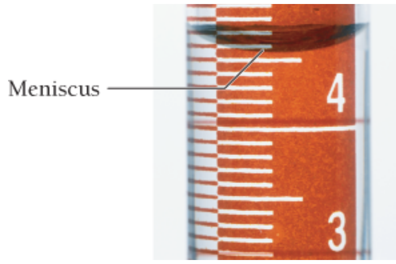
Consider the following reported number:

The first three digits are certain; the last digit is estimated.

The number of digits reported in a measurement depends on the measuring device. Consider weighing a sample on two different balances (Figure E.4). These two balances have different levels of precision. The balance shown on top is accurate to the tenths place, so the uncertainty is ± 0.1 and the measurement should be reported as 10.5. The bottom balance is more precise, measuring to the ten-thousandths place, so the uncertainty is ± 0.0001 and the measurement should be reported as 10.4977 g. Many measuring instruments—such as laboratory glassware—are not digital. The measurement on these kinds of instruments must also be reported to reflect the instrument's precision. The usual procedure is to divide the space between the finest markings into ten and make that estimation the last digit reported. Example E.2 demonstrates this procedure.

Example E.2 Reporting the Correct Number of Digits

The graduated cylinder shown here has markings every 0.1 mL. Report the volume (which is read at the bottom of the meniscus) to the correct number of digits. (*Note*: The meniscus is the crescent-shaped surface at the top of a column of liquid.)



SOLUTION

Since the bottom of the meniscus is between the 4.5 and 4.6 mL markings, mentally divide the space between the markings into 10 equal spaces and estimate the next digit. In this case, the result is 4.57 mL.

What if you estimated a little differently and wrote 4.56 mL? In general, a one-unit difference in the last digit is acceptable because the last digit is estimated and different people might estimate it slightly differently. However, if you wrote 4.63 mL, you would have misreported the measurement.

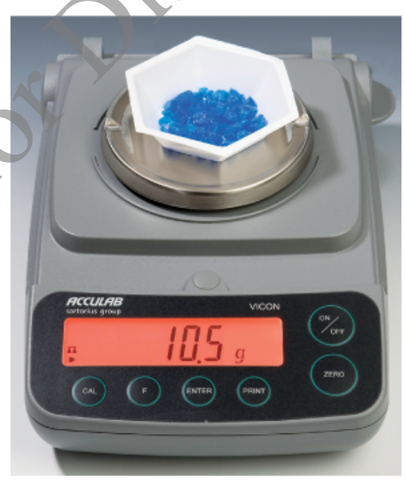
FOR PRACTICE E.2

Record the temperature on this thermometer to the correct number of digits.

Figure E.4 **Precision in Weighing.**

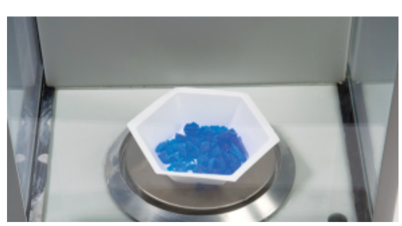
(a) This balance is precise to the tenths place. (b) This balance is precise to the ten-thousandths place.

Estimation in Weighing



(a)

Report as 10.5 g



(b)

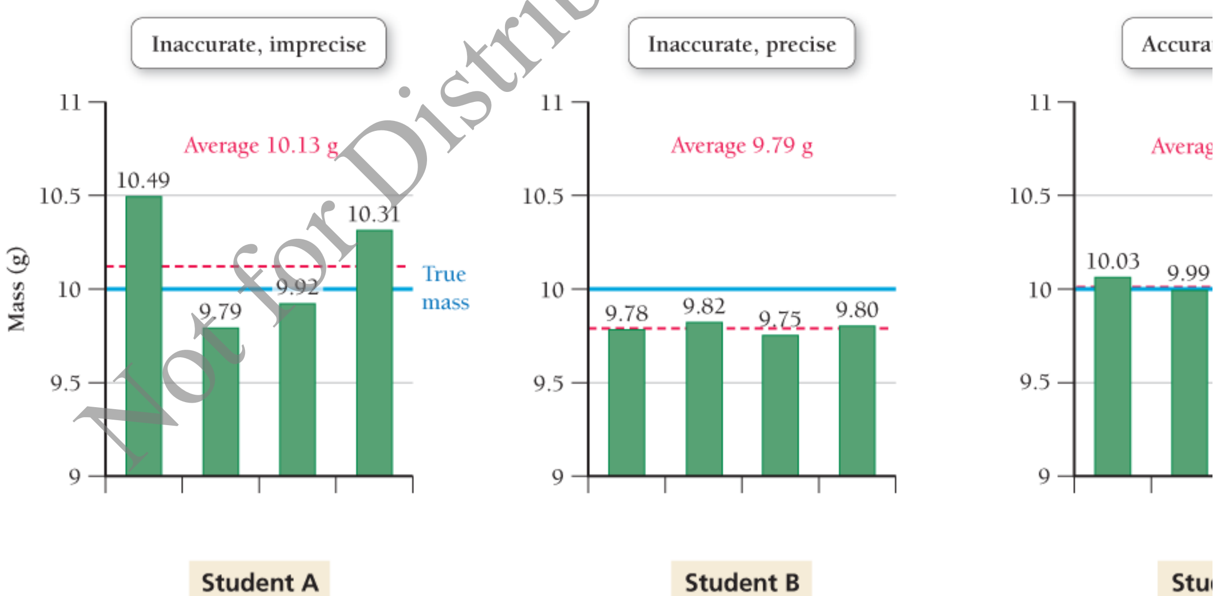
Report as 10.4977 g

Precision and Accuracy

Scientists often repeat measurements several times to increase their confidence in the result. We can distinguish between two different kinds of certainty—called accuracy and precision—associated with such measurements. **Accuracy** refers to how close the measured value is to the actual value. **Precision** refers to how close a series of measurements are to one another or how reproducible they are. A series of measurements can be precise (close to one another in value and reproducible) but not accurate (not close to the true value). Consider the results of three students who repeatedly weighed a lead block known to have a true mass of 10.00 g tabulated below and displayed in Figure E.5 .

Figure E.5 Precision and Accuracy

The results of three sets of measurements on the mass of a lead block. The blue horizontal line represents the true mass of the block (10.00 g). The red dashed line represents the average mass for each data set.



	Student A	Student B	Student C
Trial 1	10.49 g	9.78 g	10.03 g
Trial 2	9.79 g	9.82 g	9.99 g
Trial 3	9.92 g	9.75 g	10.03 g
Trial 4	10.31 g	9.80 g	9.98 g
Average	**10.13 g**	**9.79 g**	**10.01 g**

Measurements are precise if they are consistent with one another, but they are accurate only if they are close to the actual value:

- Student A's results are both inaccurate (not close to the true value) and imprecise (not consistent with one another). The inconsistency is the result of **random error**—error that has equal probability of being too high or too low. Almost all measurements have some degree of random error. Random error can, with enough trials, average itself out.
- Student B's results are precise (close to one another in value) but inaccurate. The inaccuracy is the result of **systematic error**—error that tends toward being either too high or too low. In contrast to random error, systematic error does not average out with repeated trials. For instance, if a balance is not properly calibrated, it may systematically read too high or too low.
- Student C's results display little systematic error or random error—they are both accurate and precise.