Uncertainty and Error

During experimental work, scientists make measurements. These are seldom exactly the same and are always a little different from the "true value". Such deviations from the true values are called errors.

Sources of error in measurements come from limitations in the sensitivity of the instruments or from imperfections in experimental design or measurement techniques. Errors are classified as random or systematic.

Random Error

These are always present and are from operator approximating a reading and changes in the experimental conditions. There is equal probability that the reading will be too high or too low. To minimize random error, repeated measurements are taken and the average or mean is calculated. If the same operator gets the same results, the results are said to be repeatable. If several operators get the same results, the results are said to be reproducible. See **Figure 1**. Recording the precision or uncertainty is one way of representing random error:

measurement ± random error.

Systematic Errors

These are typically present and are from limitations in instruments, technology and operator (read scientist) skill. To minimize systematic errors, careful calibration of the instruments can be done and the operator uses the best techniques. Systematic errors lead to bias, moving the measurement away from the true value in one direction or the other. See Figure 1. Recording the bias can be represented as:

measurement + systematic error **or** measurement – systematic error.

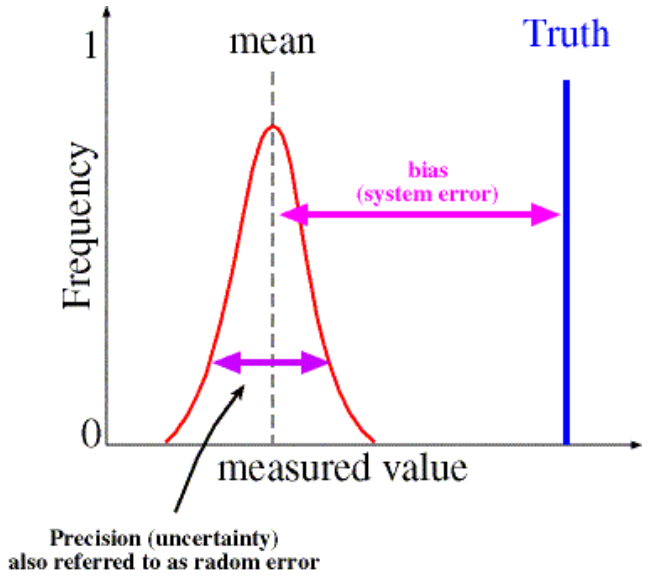

Figure 1. Graphical Representation of Random and Systematic Error. In this case, notice the bias is measurement – systematic error. Normally, only the uncertainty is reported. Systematic errors are dealt with only if the true value is known and then the % error can be calculated and discussed.

Precision and Accuracy in Measurements

Precision reflects how reproducible the measurements are while accuracy reflects how close the measurements are to the true value. Ideally, we aim for both precision (smaller random error) and accuracy (smaller systematic error). The target analogy works well. See **Figure 2**.

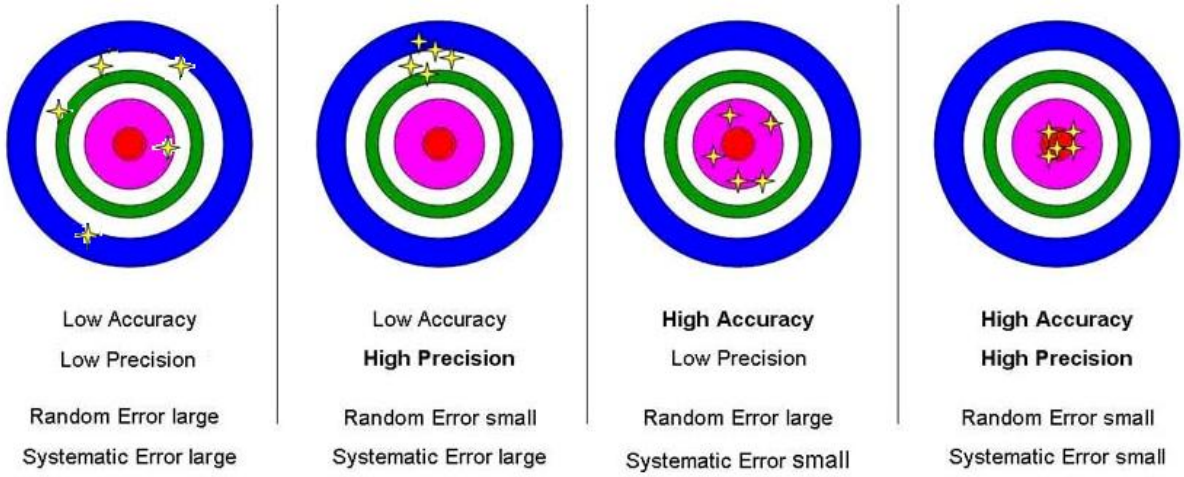

Figure 2. Precision and Accuracy. Notice that random error is related to precision while systematic error is related to accuracy.

Graphical representation can be seen in **Figure 3**.

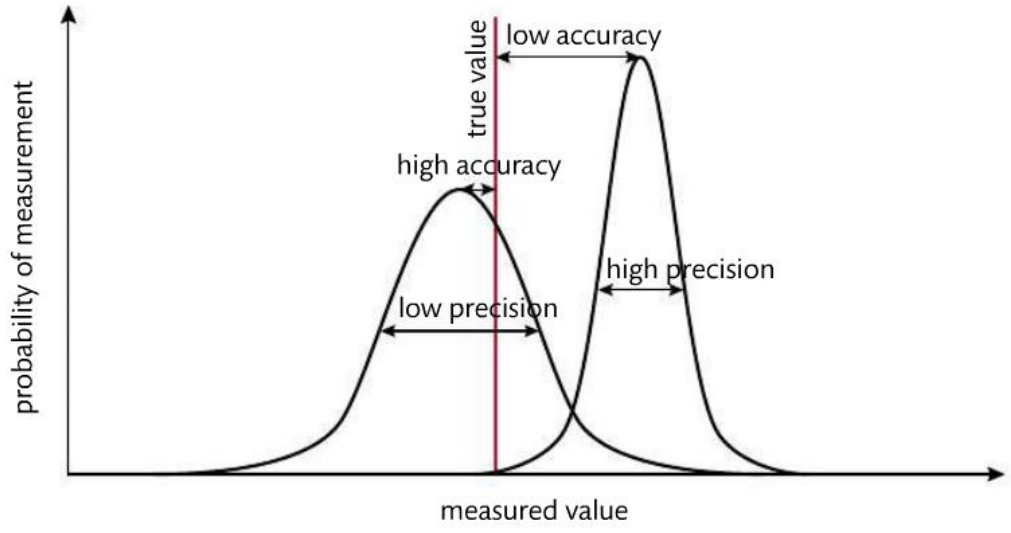

Figure 3. Graphical Representation for Precision and Accuracy. Notice that the set of readings on the left represent high accuracy and low precision. Those on the right indicate the values have high precision and low accuracy.

Discussing Errors and Uncertainties

Your conclusion is the section to take into account any systematic errors and random uncertainties. You should be able to recognize that uncertainty in one of the measurements can have a major effect on the uncertainty of the final result. The question to answer is whether or not the difference between your experimental value and the literature value can be explained int terms of the uncertainties of measurements or systematic errors.

Dealing with Errors

Scientists work to identify the errors and their magnitude. Then they work to reduce the errors with better instruments, better experimental design and by collecting lots of data. No matter how good the instruments, design and the skill level of the operator, there will always be errors! Enter the use of statistics. For our purposes, if your uncertainty (random error) is less than your % error (bias, systematic error), you have done a good job.