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Precision and the Terminology of Measurement

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Precision is often equated with other measurement terminology such as accuracy, resolution, and sensitivity. Consider the following examples of the incorrect usage of the term precision:

- "How to Measure 'g' Easily with ≈ 10^{-4} Precision in the Beginners' Lab."[1] The word accuracy should be used, not precision. Later in the article (p. 101) the term "relative error" is equated with precision. Again, accuracy is the correct word.
- In discussing approximations made in teaching introductory physics concepts, it is stated,[2] "Approximations are often presented in a manner that gives the student little insight into the level of precision presented by the approximation. Many times it is not even mentioned that an estimate is being used." Accuracy is the correct term and is, in fact, used interchangeably with precision later in the article.
- "Precision is the degree of exactness with which a quantity is measured. The precision of a measuring instrument is limited by the finest division on its scale."[3] Not true. The correct term is resolution. This same misidentification of precision with the resolution of a measuring instrument is also evident in a recent article on the teaching of errors in measurement.[4]
- "At present...the analysis of stable carbon isotopes is carried out using expensive, sophisticated mass spectrometers that can detect isotope ratio changes as small as one part in 10,000. The laser method offers similar precision, yet is simpler."[5] The term precision should be replaced by sensitivity or limit of detection.
- And finally, to further muddy the waters, a laboratory manual for introductory physics uses the terms "deviations" for precision and "errors" for accuracy.[6]

Table I. Experimental Determinations of the Speed of Light.

Year	Experimenter(s)	Speed of Light (km/s)	Uncertainty (km/s)
1675	Roemer	200,000	
1729	Bradley	304,000	
1849	Fizeau	313,300	
1862	Foucault	298,000	500
1876	Cornu	299,990	200
1880	Michelson	299,910	50
1906	Ross & Dorsey	299,781	10
1926	Michelson	299,796	4
1940	Huettel	299,768	10
1950	Berstrand	299,792.7	0.25
1951	Aslakson	299,794.2	1.9
1952	Froome	299,792.6	0.7
1958	Froome	299,792.50	0.10
1965	Kolibayev	299,792.6	0.06
1967	Grosse	299,792.5	0.05

The source of some of this confusion becomes evident when we find precision defined in the dictionary as "the quality of being precise; exactness, accuracy, etc."[7] Furthermore, in discussing errors associated with the measurement process, "...the use of statistical concepts in various fields differs and the vocabulary used is seldom identical."[8] Last, the interesting interrelationships between the four measurement terms—precision, accuracy, resolution, and sensitivity—may create additional confusion.

We present here definitions for these terms consistent with ASTM (American Society for Testing and Materials) terminology and discuss some of the relationships between them.

Precision and Accuracy

The *precision* of a series of measurements is a measure of the agreement among the repetitive determinations.[9]

This is usually quantified as the standard deviation of the measured values.

The *accuracy* of a measurement (or the average of a series thereof) is its relation to a "true," "nominal," "agreed upon," or "accepted" value. This is often expressed as a deviation or percent deviation from the known value.[9]

Precision is associated with the random errors of the measurement process, whereas accuracy is identified with systematic biases. The recent article by Ehrlich and Hutchison, "Random and Systematic Errors in Timing the Fall of a Coin,"[10] provides an excellent illustration of this difference. The one small lapse in nomenclature in the article should, however, be corrected: "For example, Schoch and Winiger have shown it possible to measure 'g' to 0.03 percent precision for physics lecture demonstrations by measuring the time of free-fall of balls with a single drop." The term precision should be replaced with accuracy. A single measurement can't provide statistics for a determination of precision.

Table I, adapted from Halliday and Resnick,[11] may help to provide a better understanding of the difference between accuracy and precision. Some measurements of the speed of light over the past three centuries are presented. Though not stated, the "uncertainty" given is presumably statistically derived from multiple measurements so that we may identify it with the precision of the measured values.

Note that the latest determinations have converged on a constant value, the present "true" or "accepted" value. This can spark interesting classroom discussions on the evolution of scientific knowledge.

Another aid in making the distinction between precision and accuracy is the classic "archery target" or "dart board" illustration such as shown in Fig. 1. The solid squares represent the locations of arrows or darts. This diagram also shows the curious relationship between the two quantities. We should note that the target labeled "Low Precision, High Accuracy" is a statistical fluke in that only the "average" of the four attempts represents high accuracy, a "bulls-eye."

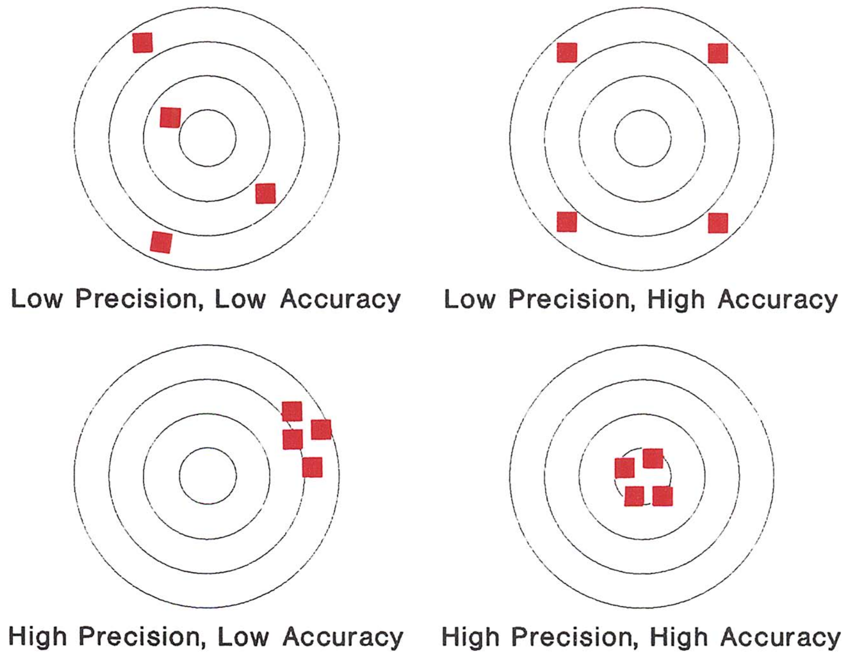

Fig. 1. Precision and Accuracy.

Resolution and Sensitivity

The *resolution* of a measuring instrument, sometimes called "readability," is the "fineness of detail revealed" by the measuring instrument.[9] This is basically the smallest increment measurable. A meterstick graduated in millimeter marks has a resolution of about ½ mm or better, since we can reasonably expect to read the difference between 2.50 and 2.55 cm. The resolution of a digital voltmeter with a three-digit display is generally expressed as ±1 in the last digit.

Sensitivity, on the other hand, is an indication of the smallest amount of a quantity measurable with the particular instrument. Can I measure a nanometer with my meterstick? Of course not. In analytical chemistry this is often referred to as the "limit of detection" (LOD). Consider the automobile speedometer as a measuring instrument. For the sake of discussion we shall consider an analog speedometer and assume that it is properly calibrated so that accuracy is not in question. Now, is it possible to discern whether the car is going 41 or 42 mph? This is a question of the resolution of the speedometer. If I start to drive and accelerate very slowly, at what speed does the speedometer just begin to register? This is a question of the sensitivity of the speedometer.

Note that resolution and sensitivity are both distinct from precision and accuracy. However, again there are interrelationships. For example:

1) Consider the following ten hypothetical measurements (units arbitrary): 9.9, 10.1, 9. 7, 10.2, 10.0, 9.8, 9.9, 10.3, 10.1, 10.0. The mean is 10.0 and the precision of the measurements as given by the standard deviation is 0.18. If, however, our measuring instrument did not have sufficient resolution to provide the first decimal place, our ten measurements may have all been "10," giving a zero standard deviation and (incorrectly) indicating phenomenal precision.

2) In spectrochemical analysis, for example, the limit of detection (sensitivity) is defined in terms of the precision (usually three standard deviations) of measurements made on the blank sample.

Discussion and Conclusions

In introductory physics classes we normally attempt to teach the students to assign an "estimate of error" to the result of a laboratory experiment. Since the laboratory measurements are usually carried out only once, this error is based on the resolution of the measuring instruments used. This "estimated error" should not be confused with the precision or accuracy of the measurement. However, by using the set of student results, we can introduce the concept of precision as an uncertainty based on the statistical evaluation of the data, i.e., calculation of the standard deviation. By comparing the result with a "known" or "accepted" value, we can establish the accuracy.

The interrelationships between these key aspects of the measurement process are interesting though sometimes perplexing:

1) You can't have accuracy without precision. However, the converse is not true.

2) The precision of a series of measurements of low resolution may actually *seem* better than that of an instrument providing a greater resolution.

3) With poor sensitivity, precision (and therefore also accuracy) will suffer for the smallest measurable quantities.

Other aspects of the measurement process that deserve to be addressed include response time, input impedance, and range, since these are also related to the four terms discussed here. They are, however, beyond the scope of this short note.

An effective introduction to the subject of statistics and measurement could well begin with the short experiment discussed by Kagan.[12] The author compares the results of coin tossing with time interval measurements in a most effective manner.

This might be followed up with the presentation of Ehrlich and Hutchison,[10] firmly identifying random errors with precision and accuracy with a systematic bias. In addition, Table I, the illustration of Fig. 1, and the "speedometer" analogies should help to clarify the differences between precision, accuracy, resolution, and sensitivity.

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