Accuracy, Trueness, Error, Bias, Precision, and Uncertainty: What Do These Terms Mean?

The *International Vocabulary of Metrology* [VIM; JCGM 200:2012, Joint Committee for Guides in Metrology (2012) www.bipm.org] has introduced terms and definitions that impact analytical chemistry and microbiology. What is the impact of these definitions? How do these terms facilitate the communication of results of measurement and the discussions of measurement science?

The answer to these questions is related to the development and improvement of measurement science, including the analytical chemistry and microbiology of AOAC. These terms allow people who make measurements, the analysts, to communicate the reportable result and its estimated uncertainty more clearly. Now that measurement uncertainty is estimated, it is used to communicate the measurement result completely to eliminate confusion, misunderstanding, and incorrect usage of the result. As we learn about making decisions with these results, having the proper, well-defined terms enables unambiguous, concise communication. This subject is relevant whenever a measurement is made, whether by an analyst in a field of chemistry, microbiology, metrology, etc.

Statisticians and metrologists are responsible for ensuring that appropriate theory and sound science support how we take measurements and report the results. We can leave those details to them, but we do need to understand the correct use of the terms.

As an example, terms concerning what we have normally called accuracy have been developed and included in VIM. These terms help us talk about some important concepts in analytical chemistry and get rid of "fuzzy thinking" that is reflected by the "fuzzy terminology" we have used historically.

As analysts we know that systematic error and random error affect our result. We know that if we repeat an analysis of the same laboratory sample or test portion, we will very likely get a different value each time. In fact, we are surprised when we get the same value. Yet we assume that there is one real, true value for the measurand; it is unknowable, but hypothetically exists. These terms allow us to speak about these realities clearly. Even the term measurand helps us communicate because it completely describes the quantity we intend to measure and must include information such as the analyte, the units of measure, the matrix, whether it is an empirical (operationally defined) method, or method conditions.

Meanwhile, analysts need to use the correct terms for method validations. Understanding the correct term allows better communication amongst analysts, with customers, and with statisticians. These are some of the reasons we need to understand the vocabulary of measurement science.

The terms accuracy, trueness, error, bias, precision, and uncertainty are listed in Table 1. For each term, a brief description of its meaning is given. Characteristics of the term, such as the major components it includes, how it is expressed, and where it is used, are then discussed. Finally the definition as listed in VIM is given.

These terms may best be understood by reference to Figure 1. The concepts accuracy and precision have been explained and illustrated using a dart board analogy for many years. The dart board illustration has been modified to add the new and revised terms. In the illustration, each dart board has as its center the true value. This is unknown and an accepted reference value is used in its place.

Term	What it is	Comment	VIM definition
Error	Result minus the reference value	The true error is unknowable because the true value is unknowable. Since the true value cannot be known, a conventional value, such as the reference value for a certified reference material, can be used giving a practical value for the error. It has two components, systematic and random.	2.16: Measured quantity value minus a reference quantity value
Random error	Component of error that varies in an unpredictable way	There may be more than one component (source) of random error. It is not possible to correct for random error. The size of the random error can be reduced by reporting the mean of replicate measurements. The standard deviation for the mean is its standard error of the mean.	2.19: Component of measurement error that in replicate measurements varies in an unpredictable manner
Bias	Systematic error Component of error which varies in a predictable way	There may be more than one component of systematic error. Bias can be estimated by the difference of the mean value of several measurements from the reference value. It can be estimated by measuring the value of one or more reference materials several times under repeatability or intermediate precision conditions and calculating the mean. The difference between the mean and the reference value is the bias. In many cases, a correction can be used to remove the effect of known systematic errors (bias). Bias is determined in the method validation experiments.	2.18: Estimate of a systematic measurement error
Trueness	Closeness of agreement between the average of an infinite number of results and a reference value	Trueness is a hypothetical indication of the ability of the method to yield results close to the expected reference value. It is hypothetical because an infinite number of results cannot be obtained and the true value cannot be known. Thus, trueness cannot be expressed numerically. Accuracy should not be used for trueness.	2.14: Closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value
Accuracy	Closeness of agreement between a result and a true value	Accuracy describes how close a single result is to the true value. Therefore, accuracy includes the systematic error and the random error that impacts that result. Stated another way, accuracy includes trueness and precision. Since the true value is not known, accuracy cannot be given a numerical value, but is a descriptive and comparative term for a method. A method that has less random error, or a smaller bias, or both is called "more accurate."	2.13 (3.5): Closeness of agreement between a measured quantity value and a true quantity value of a measurand
Precision	Closeness of agreement between results obtained by replicate measurements on the same object under specified conditions	Precision is related to random errors only; see random error above. Precision is usually expressed numerically as a standard deviation or variance. The specified conditions can be, for example, repeatability, intermediate precision, or reproducibility conditions.	2.15: Closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions
Uncertainty		Measurement uncertainty (MU) comprises many components, including random components and the uncertainty associated with the systematic effects. MU is expressed as standard uncertainty which is a standard deviation. MU is the parameter that includes uncertainties from the most possible effects; it is the most suitable way to describe the accuracy of results.	2.26: Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

The dots on each board represent individual values.

The x axis is precision, expressed as a standard deviation, which decreases in quantity (i.e., improves) as one moves to the right. In dart boards (b) and (d), the dots are more tightly grouped than in boards (a) and (c). The y axis is trueness, which improves as one moves up the axis. The values in (c) are not centered on the middle of the dart board, and in (a) the values are centered on the middle of the dart board, illustrating better trueness.

Error is shown as the difference between a single dot, or value, and the center of the board. Bias is shown as the difference between the middle of several dots and the center of the board. The board with the best accuracy is (b).

Conclusion

The terms accuracy, trueness, error, bias, precision, and uncertainty now allow us to clearly discuss our measurements. Consider the following discussion.

Without the improved terminology: The method was improved and the accuracy is better.

With the improved ter-

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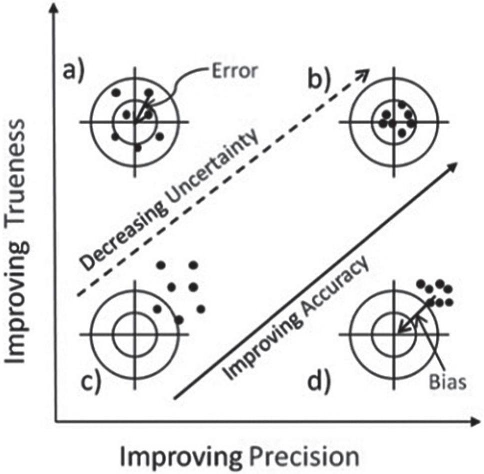

Figure 1. The meaning and inter-relationship of the terms trueness, accuracy, bias, error, uncertainty, and precision are depicted using the dart board analogy to illustrate the center of a target and the spread of values.

minology: The method was improved in that the precision (repeatability) was reduced; precision standard deviation was reduced from 1.0 to 0.5%. Hence the measurement uncertainty was also reduced. The bias was reduced from 0.5 to 0.1%. Hence the trueness was improved. Individual results from the improved method are more accurate.

The examples show how the terms and the VIM definitions allow us to communicate clearly. ■

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