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Understanding the meaning of accuracy, trueness and precision

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Abstract Clear definitions of basic terms, used to describe the quality of measurements, is essential for communication among scientists as well as when reporting measurement results to clients. Even if appropriate definitions are given in international standards and guidelines, the understanding of some basic terms sometimes proves difficult. The reasons for this are various, e.g., the same words being defined rather differently in encyclopaedias and in international standards as well as concepts, well established in some languages, that may be relatively new in other national communities and at large in the international one. Here we present a matrix intended to clarify the relationships between the type of error affecting an analytical measurement, the respective qualitative concepts (performance characteristics) and their quantitative expression.

Keywords Terminology · Accuracy · Trueness · Precision

The understanding of the meaning of some basic terms (i.e. accuracy, trueness and precision), used to describe the quality of measurements, has sometimes proven difficult, even within the analytical community, mainly because:

a. the same words being used with conflicting meaning, e.g. *precision* expresses spread within the analytical community but in common language can be synonymous of *accuracy;*[1]
b. the qualitative concepts of *accuracy* and *trueness* are well established in some languages (German: *Genauigkeit* and *Richtigkeit,* Swedish *noggrannhet* and *riktighet*), but relatively new in some national communities (e.g. Italian) and at large in the international one [1]. The misuse of the word *accuracy* in place of *trueness* in most analytical publications in the field of analytical atomic spectrometry was recently addressed [2].

In this context, it should also be mentioned the difference existing between common usage of the word "error" and how it is used in the GUM [3]. According to the GUM, *Error is an idealized concept and errors cannot be known exactly* [Note GUM §3.2 and further reading in Annex D]. For example, the standard deviation of the mean, sometimes indicated as standard error of the mean, expresses a quantitative evaluation of the uncertainty of the mean deriving from casual effects and not the exact value of the error of the mean, which is not known.

In addition to the appropriate definitions, given in international guidelines and standards and reported in Table 1, the matrix presented in Fig. 1 is intended to clarify the relationships between the type of error affecting an analytical measurement, the respective qualitative concepts (performance characteristics) and their quantitative expression.

Table 1 Definitions of qualitative terms describing the performance characteristics of a measurement

Accuracy of measurement	Closeness of agreement between a quantity value obtained by measurement and the true value of the measurand (3.5) [6]
Precision	The closeness of agreement between independent test results obtained under stipulated conditions (3.14) [7, 8]
Trueness	The closeness of agreement between the average value obtained from a large series of test results and an accepted reference value (3.12) [7, 8]

[1] Precision–The quality, condition or fact of being exact and accurate. Pearsall, J (ed), The new Oxford Dictionary of English, Oxford University Press 1998.

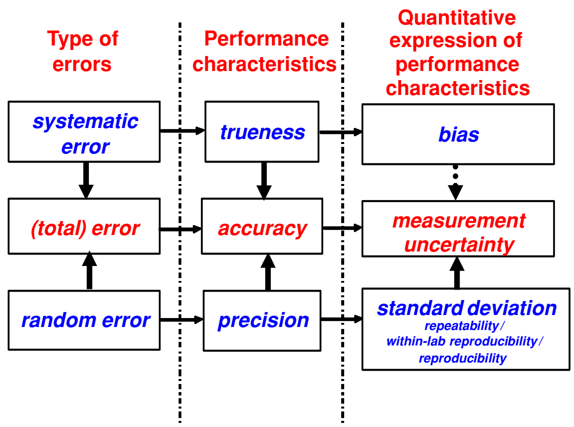

Fig. 1 Relationships between type of error, qualitative performance characteristics and their quantitative expression

For example, the effect of random errors on a measurement is expressed as the performance characteristics "precision", which can be quantified as the standard deviation of repeated measurements on the same sample using the same method. In more detail, precision is expressed as:

(1) *repeatability*, when the least changes are allowed *(*e.g. assays carried out over a short period of time, by the same analyst using the same instrument, etc.)
(2) *within-laboratory reproducibility (intermediate precision)* when, within the same laboratory, any relevant influence factor is allowed to vary *(*e.g. assays carried out over a longer period of time, by different analysts, using different reagent lots, in different environmental conditions and even using different instruments of the same specifications)
(3) *reproducibility,* when the precision of the method as applied in different laboratories is taken into account (e.g. assays carried out according to a specified statistical design by different laboratories applying the same analytical protocol as part of an interlaboratory collaborative study).

In a similar way, if one or more influence quantities cause effects on the measurement result that can be identified as systematic components of the error (*systematic error*), such effect is expressed by the performance characteristics *trueness*. This can be quantified as *bias*, i.e. the difference between the average of several measurements on the same sample (e.g. a Certified Reference Material) and its (conventionally) true value. The significance of such difference must be assessed by appropriate statistical tests against the precision of the bias measurement and the reliability of the value chosen as reference. Therefore, experimental precision (as the standard deviation of the mean) and the uncertainty of the reference value are components of the uncertainty of the bias estimate, even when no significant bias is observed.

Since variations of influence quantities may affect a measurement result in both random and systematic ways, the qualitative performance characteristics of the measurements – *accuracy* – includes both trueness and precision, just as the general term *fruits* includes both *apples* and *oranges*. It would sound peculiar to talk about *fruits and oranges* and, in the same way, it is inappropriate to use the wording *accuracy and precision* instead of *trueness and precision*.

Accuracy is a qualitative performance characteristics, expressing the closeness of agreement between a measurement result and the value of the measurand. A quantitative estimate of the accuracy of a result is essential to define the degree of confidence that can be placed in it and the reliability of the decisions based on such result. Such parameter is the *measurement uncertainty,* which describes "the dispersion of the values that could reasonably be attributed to the measurand", often expressed as a standard deviation (standard uncertainty) or as an interval including a larger fraction of such values (expanded uncertainty), obtained by multiplying the combined standard uncertainty by a specified coverage factor (k). Guidance has been provided to use both the information provided by repeatability/reproducibility and trueness (bias) estimates for the evaluation of the uncertainty of measurement [4, 5]. The broken line in Fig. 1 takes into account the on-going debate on the contribution of bias components to measurement uncertainty.

Although the matrix in Fig. 1 may not be exhaustive, the Authors hope it can provide a simple and visual way forward to stimulate the discussion among all those involved in the understanding of how these basic concepts are related and how they should be used within the analytical community.

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