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Measurand: a cornerstone concept in metrology

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Abstract
This paper proposes to discuss some concepts whose importance is fundamental to any theory of measurement. From the epistemological point of view there is a very significant inconsistency in the concept of measurand contained in the GUM. According to the model adopted by the GUM, a particular measurand remains the same measurand after a change in its definition, notwithstanding the fact that new conditions had been included or other pre-existing conditions had been altered in the definition. And also notwithstanding the very probable fact that, in consequence, the uncertainty component associated with its definition had been changed. The problem that arises from this theoretical model is that a particular measurand is not completely characterized by a precise and unique definition. Instead, it is considered an ‘ideal’ utopian particular concept to which would converge a specific series of ‘measurands’ (more properly their definitions), continually redefined in an infinite succession. Such a theoretical basis seems very inappropriate: the model intends to determine the uncertainty of uncertainly defined particular measurands. Of great relevance is the proposal of a new definition for the concept of measurand, a concept that interfaces the realms of Metrology and experimentation. Other concepts have been created or redefined with sufficient precision and selectivity to consider some aspects that remain somewhat confused in the model of measurement currently applied.

1. Introduction

A comprehensive knowledge of the deeper significance of the concept of measurand is crucial to the understanding of the measurement processes. In the framework of any scientific field, however, the essence of things may only be determined and perceived by their unequivocal definition, seeing that this essence is continuously criticized by scientists and interchanged among them. In the course of a discussion the perception of the things could differ from person to person, but they must talk about the same things during this process. In order to realize the main task of this work, consider the delicious and enlightening excerpt from Fox et al [1]:

Take, for example, measures of length, perhaps the simplest type of all. [...] but eventually we are up against the question: ‘What is the length of an object?’ Even a piece of polished steel has its rough edges, though we may need a microscope to see the roughness. Possibly the definition of the length of such a piece should be the distance between the [...] lines which are perpendicular to the axis of the bar and which just touch the outermost projections. This does not solve the problem, however, for the roughness along the long edges of the bar prevents the exact determination of the axis. Furthermore, if we could carry our measurements to a precision corresponding to the molecular level, we would find that our rough edges are in motion, making all earlier problems seem trivial.

Similar considerations may be seen in Mari [2] and in Phillips et al [3].

The main concept of Metrology, the measurand, albeit the proper subject of the measurement processes, is a concept with very serious definitional deficiencies. This happens even within the scope of the most important and internationally widespread metrological publication—the Guide to the Expression of Uncertainty in Measurement [4], hereafter referred to as GUM. The problem is that the persistence of this ill-conceived concept of measurand brings great difficulty to the construction of a robust concept of
uncertainty in measurement. Important references to this work are also the ‘International Vocabulary of Basic and General Terms in Metrology’ [5], referred to as VIM2, and the recently published ‘International Vocabulary of Metrology—basic and general concepts and associated terms’ [6], referred to as VIM3, after Wallard [7]. The term measurand is written in italicized Arial font whenever the implied reference is the concept as treated in the GUM.

The measurand, in the GUM, is not a concrete concept. The understanding that the GUM associates with measurand, the most prevailing understanding within the scientific community, gives to it an intangible character, the status of first principle or primitive concept as is, for instance, the point concept in Geometry. In the realm of Metrology, however, the concept of measurand stands in a central position: it is the conceptual construct about which we want to have some knowledge.

It is noticeable that an appealing and frequent sentence (B.2.3, D.2.1, D.3.1, D.3.4) in the GUM is ‘... (to be) ... consistent with the definition of the measurand’. Curiously, there is, on these occasions, an allusion to the possibility of an objective definition of measurand, a form that the GUM does not contemplate: the definition is never complete. A concept that cannot be completely described without an infinite amount of information [GUM D.1.1] cannot, definitely and definitively, be defined. So, this work proposes new definitions for the measurand and other related concepts. These definitions seem more convenient and appropriate for scientific works and constitute a more secure scientific basis for Metrology, being independent of statistical viewpoints: Metrology is not Statistics.

Section 2 discusses the concept of measurand as treated in the GUM. Careful definitions are proposed in section 3, in appropriate order, for some basic concepts. Section 4 presents a discussion of these concepts and their interrelations in the context of measurement, considering the larger framework of experimentation. Some important particular aspects of the science of measurement are discussed in appendix A.

2. The concept of measurand in the GUM

Dealing first with the concept of uncertainty, it seems that the GUM does not give due importance to the need for treating conveniently the concept of measurand. We can see in GUM 2.1: ‘…The definitions of the most important terms specific to this Guide are given in 2.3.1 to 2.3.6.’. Significantly, the definition of measurand is not found among these ‘most important terms’. A definition of measurand is only given in an annex (GUM B.1: ‘…general metrological terms relevant to…’). So, the Guide considers the concept of measurand merely relevant. Although the Guide deals primordially with uncertainty in measurement, this is an inappropriate standpoint, because every measurement is accomplished to denote quantity values for a measurand. As the main concept in measurement it is indispensable to define it well. The definition of measurand is given in GUM B.2.9: ‘Measurand: particular quantity subject to measurement.’ The same form is used in VIM2 (definition 2.6) with a dispensable complement: ‘Measurand: the subject of the measurement’. This statement asserts a rhetoric central importance for measurand, but it is essentially non-operational. The third edition (VIM3) [6] proposes a new definition for measurand: quantity intended to be measured’. As noted by Mari [2], this form ‘…emphasizing the fact that what is declared to be the property under measurement could differ from the actually measured property.’. This is still an empty concept: it does not say anything about the characteristics of the measurand, or even about the nature of its characteristics. These definitions are as vague as the form ‘solid material intended to be eaten’ would be to define nourishment.

Three considerations are relevant here: the above definition vulgarizes the very sense of the verb ‘to define’. First, the definition of measurand is based entirely on the expression ‘particular quantity’. The definition of ‘particular quantity’ (if one calls it definition) is precariously established by exemplification (GUM B.2.1 NOTE or VIM2 1.1: a series of three examples), as well as its differentiation from ‘quantity’ (in a general sense). VIM3 does not define particular quantity. It operates the concept of quantity only, and presents (1.1 NOTE 1) a table with several specific levels for this concept. Second, the definition of measurand only reminds us, and remarks that, a particular quantity is (or begins to be) called measurand when submitted to measurement (or when intended to be measured) [6]). This procedure is insufficiently rigorous and does not consider that the existence of a measurand, at the conjectural level, cannot depend on the fact that it be (or not) subjected (at any time) to measurement. Finally, in the sense proposed by the GUM there is no relevant difference between the concept of measurand and the concept of particular quantity (or quantity, in [6]).

A particular measurand is something that cannot, even in principle, be precisely defined: infinite conditions will always remain to be specified. In this way, every time a hypothetical particular measurand is referred to, there will be different and infinite definitions to express it. All these definitions will be associated with the same measurand, but the fact is that none of them can be considered, conceptually, a measurand. This is a curious and impossible case in which there are infinite and different definitions for the same concept. But what constitutes the measurand in the GUM will always and only be that ideal concept in which the successive definitions would converge. An example of that conceptual confusion is given in GUM D.3.4: ‘…To obtain a value of the quantity in question having a smaller uncertainty requires that the measurand be more completely defined’. That is, in a curious way, one intends that the measurand be redefined, but even after the redefinition and the establishment of the new definition it would continue to be the same measurand.

1 Suppose one ideal utopian measurand $M_\infty$ that, according to the GUM, may only be specified by a set $D_\infty$ of infinite conditions. Suppose now three concrete definitions for this measurand, $D_1$, $D_2$ and $D_3$, with 1, 2 and 3, respectively, relevant conditions. Clearly, $D_1$, $D_2$ and $D_3$ will refer to measurands $M_1$, $M_2$ and $M_3$ with different intrinsic uncertainties. So, $M_1$, $M_2$ and $M_3$ will be different from each other and then it is impossible that all three are equal to $M_\infty$ at the same time.

2 This point is, somehow, considered in GUM3 2.27 NOTE 2 (see appendix A, clause 1)
If we recognize the fundamental fact that we cannot specify an infinite amount of information, we should also recognize that any measurand will always be, in practice, specified without infinite other possible specifications of states, parameters, conditions etc. The hypothetically possible influences of these neglected specifications are responsible for what the GUM calls ‘uncertainty component . . . (due to) . . . an incomplete definition of the measurand’. These components ‘. . . may be or may not be significant relative to the accuracy required . . . ’. See also the NOTE in GUM 3.1.3. In this sense, due to its incomplete definition, the measurand will have a group of associated values, and not just a single value.

The reference ‘incomplete definition of the measurand’ [GUM D.3.4] carries two parallel interpretations: in a first sense it may indicate that the person responsible for the description of the measurand was unable to make a more complete and convenient description. In this case, supposedly, the measurand that one intends to define is not exactly the one that was in fact described. Here, the reference ‘incomplete definition of the measurand’ is properly used. In another sense, the same reference could refer to the general fact that all measurands are, ipso facto, incompletely described: the description of the measurand is, maybe, convenient, but it is, nevertheless, incomplete. Here the reference ‘incomplete definition’ is not pertinent.

Strictly speaking, in the theoretical context established by a definition of measurand similar to that adopted by the GUM, there is no justification for the appearance of an uncertainty component due to ‘incomplete description of the measurand’. This happens only when the conceptual delimitation consigned in GUM 1.2 and in GUM 3.1.3 is not seriously considered. This fact evidences the conceptual inadequacy of the definition of measurand adopted by the GUM to treat the multiple viewpoints from which a specific quantity may be considered. This multiplicity of viewpoints emphasizes the important experimental reality characterized by the fact that the same specific quantity is represented, in different contexts, by different (although convenient) forms or definitions of measurand.

In the Introduction of the GUM we may see: ‘. . . and the appropriate corrections have been applied, there still remains an uncertainty about the correctness of the stated result, that is, a doubt about how well the result of the measurement represents the value of the quantity being measured.’ The same idea is expressed in GUM 3.3.1. This is to say that the GUM seriously admits the real existence of something like ‘the value of the measurand’, in the sense that any measurand could have, at least in principle, an exact value. This exact value would be inaccessible due to deficiencies of the measurement processes. Such an idea asserts that the declared final uncertainty is related only to the measurement processes. This is a good approximation only when the uncertainties associated with the measurement processes are strongly dominant. See, regarding this, VIM3 2.11, true quantity value, NOTE 3.

The GUM says (in 3.1.3) that the expression ‘value of the measurand’ is to be used only for single-valued measurand (see also GUM 1.2). Of course, limiting Metrology only to cases of this type would restrict excessively its field of application. Moreover, we see in GUM D.3 (mainly in D.3.4) that the GUM did not proceed precisely as it prescribes. At this point, overlooking the existence of more than one value consistent with the definition of the measurand, the GUM makes reference to ‘an incomplete definition of the measurand’.

There is a fundamental, yet non-explicit, supposition that permeates all the work resulting in the GUM: the greatest possible accuracy is desirable for any measurand. This argument is not consistent with the definition of the term Metrology (in [5]: ‘Science of the measurement’, or in [6]: ‘science of measurement and its application’), which would include ‘all theoretical and practical aspects of measurement, whatever the measurement uncertainty and field of application’.

3. Proposed definitions for some concepts in measurement

This section presents formal definitions for some basic and important concepts. These definitions were designed to be sufficiently precise and comprehensive to be useful in any measurement context. Compare them, when possible, with corresponding definitions in the GUM or VIM.

Quantity. Any attribute (aspect, property or quality) of a body or system (gas in a container, pencil, standard end gauge), of a concept or entity (person, strain tensor, proton), of a state or phenomenon (solidification of a sample, spins alignment, explosion of a bomb), or of their components, that may be distinguished qualitatively and univocally and may assume manifestations that are quantitatively different and determinable.

Measurable quantity. Any quantity to which one may attribute the mathematical categories of ‘equal to’, ‘larger than’ and ‘smaller than’, and for which a specific amount can be defined as standard, operationally referenced to the corresponding unit, which is defined and adopted by convention.
It is necessary to establish feasible and operational procedures for comparison of particular amounts of the quantity with the defined standard amount. In the expression ‘measurable quantity’ the qualifier should be understood as ‘measurable in principle’, because at any specific time there will be quantities that will remain unrecognisable as measurable quantities, e.g. for today, the intensity of a passion. Some quantities will, in addition, be attributes of entities that will only exist in the future, while others will be lost forever. The definition clearly excludes vectors, tensors and matrices as measurable quantities. They are, however, entities that possess measurable components.5

Specific (measurable) quantity. Measurable quantity whose nature and reason for existing were associated with a system, entity or phenomenon, being then, and in consequence, understood and ascribed as a specific attribute of that phenomenon, entity or system.

Although measurable in principle, a particular specific quantity, to be, in fact, measured, should be available and accessible in the form of a realized measurand and it must have been previously defined as a measurand.

Support-system. Constitution, extent, conformation and/or orientation, in time and space, of the body, entity or phenomenon (or part of them) in question, considered as the actual system from which a specific quantity of interest is an attribute.

The support-system should be clearly established by the Contextualized Specific Quantity (see below) and clearly reported in the measurand’s definition. Of course, when the support-system is established, it does not make sense to consider, in addition, the time and space quantities that circumscribe it as influence quantities or, rather, input quantities in a measurement model (VIM3 2.50). For example, if we are interested in the electric current flowing in a wire during an interval of 15 minutes, possible differences in quantity values obtained by the measurement during this time interval are not to be attributed to a time variable, because all these quantity values are proper values of the measurand.

Contextualized specific quantity. Specific quantity considered from the very peculiar experimental perspective that dictates the uses and applications one intends to give to results of eventual measurements to which an associated measurand will be submitted. The contextualized specific quantity (CSQ) manifests itself as an appropriate and comprehensive understanding of all aspects of application that eventual results of measurement could provide.

5 The new version of the VIM [6] considers vectors and tensors as quantities (VIM3 1.1 NOTE 5). But that stated in NOTE 5 disagrees with that stated in the main entry of the definition.

All efforts at defining, measuring, calculating, and expressing the results are promoted to arrive at a better knowledge of the contextualized specific quantity. The CSQ does not constitute in itself a strictly metrological concept. It is usually related to scientific, economic or technical adequacy and convenience. It makes a connection between experimentation and measurement contexts through the definition of one or more suitable associated measurands. The apprehension of what constitutes the CSQ is not realized, in any particular situation, by a formal, complete and operational definition, as happens with the measurand. The CSQ delineates also the constitution and structure of the support-system. The knowledge of the CSQ permits us to specify, on a reasonable basis, an ‘upper limit to the uncertainty of measurement’, nominally target measurement uncertainty, a new concept defined in VIM3 2.34.

Measurand. Specific quantity characterized and particularized by a finite and unequivocal collection of specifications. This collection defines and characterizes the peculiarities of the contextualized specific quantity that one intends to measure and/or whose properties and behaviours one intends to know or discuss. The collection characterizes, in addition, the corresponding support-system.

The particularities of use of the system whose attribute is being studied are represented by the CSQ and they determine the particularities of the possible applications of the measurement result. These are the circumstances that determine the number of (explicit) conditions to be enrolled in the definition of an associated measurand. The specifications may include indications about physical states, geometrical-topological and time restrictions, space orientations, values of parameters, procedures, methods to be carried out, etc. A complete specification involves also the delimitation of the intervals in which those indications are defined. It is assumed that all relevant aspects of the Contextualized Specific Quantity are taken into account in the definition of an associated measurand (please note the change in font). Conditions not mentioned are believed to be irrelevant.

Realized measurand. System assembled or embodied in such a way as to represent the measurand according to the specifications given in its definition.

The preparation of the system may involve the accomplishment of compulsory (established in the definition of the measurand) or elective operations and it may also include instructions on techniques and strategies of measurement. Above all, the metrologist needs to take into account the correct understanding of the associated Contextualized Specific Quantity. An infinite number of realized measurands may be identified with a single definition of measurand. Thus, any measurement result is primarily related to
the associated realized measurand, and secondarily with the measurand.

**Inherent uncertainty of the measurand.** Contribution to the measurement uncertainty arising exclusively from the definitional particularities of the measurand.

The inherent uncertainty (IU) is determined by the number of conditions associated with the definition of the measurand and the respective degrees of restriction established by these conditions. The IU is a lower limit for the measurement uncertainty. This limit can be reached by a continuous refinement in the process of measurement. Any CSQ has a family of associated measurands, and each measurand in this family has its own IU.

### 4. Discussion

The first four concepts defined in the last section are of general character and present no difficulty.

#### 4.1. Contextualized specific quantity

The importance of and necessity for defining the concept of contextualized specific quantity are due to the fact that the very same specific quantity can be viewed from different perspectives, depending on the intended application. The CSQ is the specific quantity that one intends to know or discuss, and that moves our metrological interest, but whose significance is not determined, in general, by strict metrological interests. It concerns the question: to what past, present or future situations is the knowledge of its associated measurand relevant, and how? This question is grounded in common sense. Prior to the phase of defining the measurand, we need to achieve a good (convenient) understanding of the CSQ.

To get such understanding it is important to know, in any specific case, the maximum and the minimum temperature, the humidity, pressure, illumination or vibration in which the device under study can work, what portion of the device is to be considered as the support-system, its position when in use, the acceptable degree of contaminants, and so on. Given a singular specific quantity associated with a device (e.g. the temperature in a climatic chamber), the number of CSQs that may be appropriately associated with it will be equal to the number of different imagined applications for the device with respect to that quantity. Moreover, there are an infinite number of measurands that may be associated with each CSQ. Incorrect understanding or inadequate formulation of the contextualized specific quantity may invalidate the subsequent use of the measurement results.

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6 When FIFA is dealing with the definition of the official length for the football field, the Contextualized Specific Quantity is of sporting interest. If BIPM is dealing with the definition of the temperature for a new fixed-point cell, then the contextualized specific quantity is of strict metrological interest.

7 A weaker statement may be seen in Pavese [8]: ‘There are as many measurands as there are artifacts…’

8 The third version of VIM [6] considers a similar concept, which is briefly mentioned in GUM D.3.4. See appendix A, clause 1. The name IU is retained here by argumentative convenience and to avoid confusion: the IU is applied to a different concept of measurand.

9 See appendix A, clause 3, for additional discussion on this important subject.

10 If parallel surfaces of a block have imperfections of the order of 0.1 mm, consecutive measurements of its length will differ by values of this same order. Recurrent variations of input quantities in the measurement model contribute only marginally to these differences. The main contribution to them is associated with those imperfections, property of the support-system, and, supposedly, taken into account in the CSQ.
(4) Tolerable variations or fluctuations of relevant conditions (e.g. input quantities in the measurement model, trepidation or positioning of the support-system) not specified in the definition of the measurand.

4.3. The measurand

The fundamental contribution of this work is the proposal that a circumsstantial measurand is to be understood exactly as it is (or has been) specified. Therefore, measurand is defined as a specific quantity particularized by a finite and determinate group of specifications. This definition sets clearer boundaries for the concept, allowing a quite unequivocal separation between entities that are measurands and entities that are not measurands. On the other hand, for each measurand will just correspond one group of specifications, and vice-versa. We are then freed from the elusive and diffuse character11 of the concept of measurand adopted by the GUM. Finally, each particular measurand will have a unique and determined value of related inherent uncertainty.

A detailed description of the measurand and agreement about all the delimiting conditions, including implicit specifications, are important to avoid problems, mainly the waste of time and energy on endless discussions about eventually non-concordant results of measurements made by different laboratories on measurands that may be, after all, different measurands. On the other hand, special care should be dedicated to the preparation of the measurand. These two aspects of measurement are quite different. In the first case the supposedly identical measurands may be, in fact, different (different definitions). In the second case there is only one measurand, but the realized measurands could be different.

In this new context, what is usually called an incomplete description of the measurand, with its associated uncertainty, no longer exists. There will be, of course, measurands that do not conveniently represent their respective contextualized specific quantities, measurands that are badly or improperly described, but these would be problems for metrologists, not Metrology.

The inherent uncertainty of a measurand may be an important component in the final report of the uncertainty. What governs the relative importance of the IU is the relation between the degree of refinement applied to the definition of the measurand and the degree of refinement applied in the measurement. As the measurement process is refined the value of the IU becomes more and more important. This may encourage arrival at new and more refined definitions of related measurands, a fact that provides a deeper understanding of the phenomenon.

Since we have a measurand unequivocally described and associated with its description there is a non-zero IU, then associated with the ‘value of the measurand’ there will be an infinite group of values (a finite interval), and not just a single value. More importantly, neither the proper concept of ‘value of a measurand’ makes sense, when it is understood as ‘a single-valued measurand’. Both idealistic representation and quantitative specification of a measurand may be made only by an interval of values. The concept of a single-valued measurand is a valid approximation only when the inherent uncertainty is insignificant relative to the uncertainty associated with a specific process of measurement. Although some cases may exist, mainly in measurements performed at national metrology institutes, this is a rare case in the world of the measurement. This is consistent with the Uncertainty Approach for the treatment of measurement uncertainty, applied, however, in conformity with the above definition of measurand.

There is a generalized understanding that attributes solely to measurement processes the origin of uncertainty. This may be seen in Brazilian, Portuguese, French, Italian and Spanish versions of the GUM, in the proper titles of these publications.12 Although the English and German titles refer to ‘…Uncertainty in Measurement’, the other languages refer to ‘…Uncertainty of Measurement’. In the English and German versions uncertainty is merely and correctly associated with the result that arises when a measurand is submitted to measurement: it may be supposed then that part of the uncertainty value should be associated with the measurement process and part is inherent to the definition of the measurand.

Inherent uncertainty is one of the causes for the spreading of observations in repeatability or reproducibility contexts. But the IU is not to be understood as another uncertainty component to be squared summed with other components to obtain the combined uncertainty. The value of the IU may be obtained using a sufficiently refined measurement process.

5. Conclusion

The fundamental conclusion that we can extract from the issues raised in this work is that, in reality and contrarily to what the GUM asserts (see footnote 4), the measurement should be made with the sufficient accuracy of measurement required or stated by the definition of the measurand. The measurand, in its turn, should be defined with sufficient completeness relative to demands (usually of non-metrological character) dictated by the understanding associated with the contextualized specific quantity.

An underlying basic supposition in the treatment given by the GUM to the concept of measurand is that all measurements should be accomplished, for any measurand, with the highest possible metrological level, that is, with uncertainty tending towards zero. This work tries to show that this is an incorrect supposition. The correct understanding of the experimentation is that each measurement should be made with the most appropriate level, which, as seen in the last section, is dictated mainly by the context of experimentation and not by metrological considerations. It will be a mere coincidence if the most appropriate level happens to be of the same order as the

11 Curiously, this character is well remarked as positive by Philips et al [3, section 2].

12 English: Guide to the Expression of Uncertainty in Measurement; Portuguese: Guia para a Expressão da Incerteza de Medicação; German: Leitfaden zur Angabe der Unsicherheit beim Messen; French: Guide pour l’Expression de l’Incertitude de Mesure; Spanish: Guía para la expresión de incertidumbres de medición; Italian: Guida all’espressione dell’incertezza di misura.
highest metrological level found in a certain historical context. As a general theory of measurement Metrology ‘includes all… aspects of measurement, whatever the measurement uncertainty…’ [6]. We need to add: … and whatever the inherent uncertainty!

The model adopted by the GUM does not provide an appropriate terminology or procedure for differentiation between two measurands, when one of them is derived from the other by addition, subtraction or alteration of some specification conditions. This fact carries language problems on discussions involving the interpretation of how appropriately a particular measurand represents a contextualized specific quantity. Such problems have compelled the author to introduce, in the theory of measurement, unequivocal definitions for some new concepts: measurand (as opposed to measurement), contextualized specific quantity, inherent uncertainty, support-system.

This new treatment makes more precise the fundamental concepts of Metrology, making natural the treatment of any metrological context, even when a measurand has a great inherent uncertainty. It makes easier the discussion and clearer the understanding about the need and opportunity to reduce the uncertainty in specific experimental contexts. If the inherent uncertainty of a measurand represents, for instance, about 90% of the total uncertainty, it does not repay in general the effort to refine the measurement processes to reduce the measurement uncertainty. But if the context of experimentation tolerates a new interpretation for the contextualized specific quantity, then a new measurand can be defined and the measurement uncertainty reduced.

Finally, as noted by one of the referees, it is important to emphasize the necessity of making the GUM compliant with the concepts—some new, some improved—considered in the third version of the VIM [6]. The concepts discussed here relative to the concept of measurand may help in the development of an opportune new version of the GUM.

Appendix A. Comments on specific relevant topics

A.1. Definitional uncertainty concept

VIM3 [6] proposes the following definition (2.27) for the concept of definitional uncertainty:

component of measurement uncertainty resulting from the finite amount of detail in the definition of a measurand

NOTE 1. Definitional uncertainty is the practical13 minimum measurement uncertainty achievable in any measurement of a given measurand.

NOTE 2. Any change in the descriptive detail leads to another definitional uncertainty.


13 The word practical seems not pertinent here. Definitional uncertainty would be the theoretical (model dependent) minimum measurement uncertainty achievable in any practical (actual) measurement.

This new proposal for the concept of intrinsic uncertainty briefly mentioned in GUM D.3.4 is a good advance in measurement theory. But the existence of such a component of uncertainty is not supported by the GUM’s concept of measurand.

This definition of definitional uncertainty is incomplete because it states that it results from only the finite amount of detail enrolled in the definition of a measurand. In reality, the inherent uncertainty comes from the concurrency of all factors listed in section 4.2.

A convenient procedure is to consider the definition of the measurand disassociated from the measurement process, and the derived (inherent or definitional) uncertainty as an intrinsic property of the measurand. The concept can then work as an important analytical tool in several situations.

Metrology is only part of experimentation. Distinct from that stated in GUM 3.1.1 and D.1.1, the definition of a particular measurand concerns experimental interests and is a task to be considered apart from measurement: it is not a strictly metrological activity.14 On the other hand, perfect understanding of the full requirements listed in the definition of the measurand is, surely, an obligatory part and the first step of measurement. These considerations are in agreement with VIM3 [6], which avoids the above-mentioned epistemological problem by defining measurement as ‘process of experimentally obtaining one or more quantity values…’.

It is important to note that the target measurement uncertainty must be established in accordance with the contextualized specific quantity and the definition of the measurand. The value specified for it, which is an upper limit stipulated for a particular measurement process, must also comply with the lower limit given by the Inherent (definitional) Uncertainty.

A.2. Qualitative conditions in the definition of a measurand

Strictly speaking, all conditions in the definition of a measurand have quantitative character. A condition can be taken as qualitative while the context in which the measurand is defined does not demand a larger control for it. When, however, the needs that model the CSQ become more demanding, and the continuous improvement in the art-of-measurement also allows it, that condition begins to be treated as truly quantitative.

Example: A condition specifies that the length of an axis should be measured with the axis in the horizontal position. If we verify, during a series of different measurements, that the results are not influenced by the axis alignment, this condition may be taken as qualitative. We may reach, with the continuous refinement of the measurement processes, a situation in which misalignments of the axis will provoke discernible differences in the measurement results. If, at the same time, these differences are incompatible with the intended

14 If we consider the definition of a measurand as part of the measurement, the phrase ‘. . . submit a measurand to measurement’ constitutes a clear logical inconsistency. The same person may perform the definition of the measurand and its measurement, but they constitute distinct tasks.
use of the measurement result, it becomes necessary to specify the horizontality of the axis on a quantitative basis (e.g. ‘the angle between the axis and the horizontal should be smaller than 40°’).

A.3. Specifications in the definition of particular measurands and base units

A base unit (VIM3 1.10), as a very primary standard, has zero inherent uncertainty. Only base units can be specified by the use of exact values for input quantities in the measurement model. See, for instance, the definition of the second: ‘…This definition refers to a caesium atom in its ground state at a temperature of 0 K.’ [9]. However, base measurement units are not measurands (GUM D.1.1: ‘…the measurand cannot be specified by a value…’). The specification of exact values for parameters that enter the definition of a base unit is a correct procedure because it corresponds to a declaration of intention (it is adopted by convention). This procedure leaves metrologists with the possibility of continuous improvement in the state of the art of the measurement processes (the instructions and recommendations) necessary to realize the definition.

The case of the measurand is different. To submit the measurand to measurement it is necessary to specify the permitted intervals for the measurand to measurement, it is necessary to specify instructions and recommendations) necessary to realize the

in the state of the art of the measurement processes (the instructions and recommendations) necessary to realize the definition.

The case of the measurand is different. To submit the measurand to measurement it is necessary to specify the permitted intervals for the input quantities in the measurement model. It does not make sense to define a measurand for an exact value of a parameter because any specificative variable that enters the definition of the measurand is also a measurand and, as such, possesses inherent uncertainty. Therefore, it is impossible to control this variable in a pre-set exact value. The definition of a measurand with the specification of an exact value for an input quantity in the measurement model results in a quite imprecise definition, because the specification does not give an indication to the metrologists about the control limits demanded for that variable. Such a procedure may include specifications so restrictive that it renders the measurand inappropriate for experimentation. Moreover, it also makes uninteresting the proper contextualized specific quantity because the potential measurement results would only be applied in extremely restricted conditions. In other words, any scientifically significant measurand possesses non-zero inherent uncertainty.

In practice, when a measurand is specified for an exact value of an input quantity in the measurement model, it should be understood that the definition was made without a very rigid criterion. In this case previous experience should help the metrologist in the task of establishing the variable interval to prepare the measurand. This decision will depend on his discernment and the knowledge he has of the CSQ.

15 A practical strategy to specify exact values for influence quantities (input quantities in a measurement model, in VIM3) and to proceed to corrections is discussed in [2], using nevertheless a theoretical approach consistent with the GUM’s concept of measurand. Corrections should, however, be made for any form of specification of influence quantities.

16 Example: Let us suppose the following contextualized specific quantities: (a) diameter of a bowling ball—the result will be used in a classroom density determination; (b) diameter of a sphere of steel—the result will be used to sometimes the number of decimals in the specification drops a hint. The specification ‘…at the pressure 101 325 Pa…’ may indicate that the permitted values for the pressure lay between 101 324.5 Pa and 101 325.5 Pa. This is a similar context to that related in the definition of measurement result in VIM3 (2.9 note 2).

A.4. Experimentation and definition of the measurand

I have proposed a genuinely pragmatic concept of measurand. Thus, the pertinent question about any concrete definition of a particular measurand is: is it complete (suitable) for that specific situation? Here ‘measurand’ refers to measurement context, ‘situation’ refers to experimental context and ‘definition’ is the link between them.

It is not true, as stated in GUM D.3.4, that the inherent uncertainty of a measurand may be made smaller and smaller by the artifice of progressive measurand redefinition. Once a specific quantity, attribute of a particular system, and an associated CSQ have been established, there is no magic definition for any associated measurand that can make the uncertainty smaller than a minimum value. This value is related to, and is of the same order of, the width expected for the output distribution when an associated measurand is defined in infinitesimal intervals for all recognized influence quantities (VIM2) or, rather, input quantities in the considered measurement model (VIM3). On the other hand, a redefinition alters the proper character of the measurand, in such a way that, after a redefinition, we are faced with a different measurand that may or may not be related to the same CSQ. Hence, it is always important to have a clear understanding about what concept needs reinterpretation in a particular experimental context. Three situations may arise:

(1) The need for defining a new associated measurand relative to the same CSQ. Supposedly, this new measurand represents more appropriately the CSQ than the first one. There will be some interest in the comparison of their respective IUs since the associated measurands, although different, refer to the same CSQ.

(2) The need for reinterpreting the contextualized specific quantity. Suppose we have a particular CSQ and an associated measurand M. Suppose the specific quantity is reinterpreted as CSQ’ and an associated measurand M’ is defined for it. The measurands M and M’ will usually have different IUs. In this case there will be little interest in a comparison between their IUs: the measurands are different and, what is more important, refer to different CSQs.

(3) Sometimes it is indispensable to proceed to a deeper change in the context of the experimentation. This is the case when it is necessary to change the support-system or control-ball-bearing production; (c) diameter of a spherical cavity—the result will be used to calibrate an acoustic thermometer. Suppose that the definitions of the respective measurands specify that the diameters should be measured at 25°C. A skilled metrologist will know that the measurand associated with (a) may be prepared in temperatures ranged between 20°C and 30°C, the measurand associated with (b) between 24°C and 26°C and the measurand associated with (c) between 24.95°C and 25.05°C, or similar intervals.
even the system itself. For example, suppose we need a thermal workspace with uniformity of 0.30 °C to treat a sample. At first we may define the CSQ as the temperature in a cubic space of sides 30 cm centred in the interior of some furnace. We define then an associated measurand. Suppose the final uncertainty is of the order of 0.90 °C. We can reduce this value (redefining the CSQ) by choosing a smaller workspace. But this is possible only to a limited degree, because the dimensions of the workspace cannot be smaller than the dimensions of the sample. If it is impossible to reduce the uncertainty to a desirable value by making the workspace smaller, then it is necessary to change the spatial distribution of the heaters, or to get another furnace.

References


