preprint of a paper published in:
Metrologia, 52, R1-R10, 2015, doi:10.1088/0026-1394/52/1/R1

Evolution of 30 years of the International Vocabulary of Metrology (VIM)

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Abstract

Since its first edition, published in 1984, the International Vocabulary of Metrology (VIM) has become a landmark for the language of measurement, and in its three editions it has evolved together with the evolution of measurement science and its applications. This paper discusses the fundamental features of the VIM as a concept system and proposes some highlights about the way in the VIM some basic and general concepts of measurement have changed their definitions in the last thirty years.

1. Introduction

Science is a social endeavor and therefore an important task for it is communication, as enabled by language. The language par excellence for empirical sciences is mathematics, but mathematical statements become meaningful expressions of empirical sciences only because they are properly interpreted (consider the difference between $X=YZ$ and $F=ma$), i.e., because they are parts of a mathematical *model*: a structure providing a nomological network connecting mathematical constructs interpreted as non-mathematical concepts (such as force, mass, and acceleration). This is matter of domain theories, paradigmatically physics. But for a mathematical model to be applicable to individual phenomena a further interpretation is required, so to instantiate general constructs into variables or constants related to individuals (a given force applied to a body of a given mass produces a given acceleration on it): a precondition for a meaningful assignment of values to such variables and constants. That is why "the object of measurement is to enable the powerful weapon of mathematical analysis to be applied to the subject matter of science" [Campbell 1920: p.267]: "measurement is the link between mathematics and science" [Ellis 1968: p.1] because it bridges "the realm of things we say as distinguished from the realm of things we do" [Bridgman 1959: p.226]. In this task measurement is sometimes presented as the "language of science" in its turn [Mills 1997].

Despite this structural role, the linguistic dimension of / in measurement is sometimes neglected, plausibly under the assumption that instrumentation design, setup, and operation is language-independent, so that what is sensitive to language would be merely related to reporting activities (say, whether the decimal marker is chosen to be either the point on the line or the comma on the line), not really worthy of scientific research. To strengthen this position, linguistic issues are presented as mainly focused on more or less conventional lexical habits, e.g., whether the term "measure" is an acceptable substitute of "measurement", or which between "quantity value" and "value of a quantity" is preferable. Even today that the unavoidable function of models in measurement is acknowledged [Giordani, Mari 2012], and radical empiricism is refused accordingly, a vocabulary of metrology might appear first of all a list of terms, and therefore a lexical work.

The basic aim of this paper is to show that what the fundamental metrology needs nowadays from

* The author is a member of the Joint Committee on Guides in Metrology (JCGM) Working Group 2 (VIM). The opinion expressed in this paper does not necessarily represent the view of this Working Group.

terminology work[1] is primarily a *system of concepts*, i.e., a knowledge-based framework of its basic and general concepts, where the associated terms are an important but derived component. Indeed, as pointed out by [Hempel 1966: 275], “scientific statements are typically formulated in special terms, such as “mass”, “force”, “magnetic field”, “entropy”, “phase space”, and so forth. If those terms are to serve their purpose, their meanings will have to be so specified as to make sure that the resulting statements are properly testable and that they lend themselves to use in explanations, predictions, and retrodictions.”. This is particularly critical for measurement science, laden of stereotypes in its basic concepts: it has been the task more and more explicitly committed to the *International Vocabulary of Metrology* (VIM), firstly published in 1984, hence thirty years ago. This anniversary is an opportunity to analyze the current state of the language of measurement in the perspective of the three editions of the VIM published since then, witnesses of significant changes even in such a relatively short time[2] (henceforth “VIM” will designate the Vocabulary as such, independently of a specific edition, and “VIM1”, “VIM2”, and “VIM3” its subsequent editions).

The paper is structured as follows. The next Section further argues about the importance of language in science and technology, and particularly in metrology, where the VIM is an ongoing answer to the problem of producing a shared language. Section 3 presents then an overview of the VIM, its history, and the general hypotheses underlying its development, where consensus is the methodological principle of approval. The main methodological features and issues of the VIM and its development are discussed in Section 4, where the very concept of definition is discussed and some different kinds of definitions are presented and compared with each other, in particular by showing that the VIM is constituted of intensional definitions such that the defined entities are concepts, and not terms. On this basis Section 5 proposes an analysis of some important changes in contents from the VIM1 to the VIM3.

2. The role of language in measurement and the VIM

Language has many functions (a canonical reference is [Jakobson 1960], that can be read as the linguistic counterpart of the Shannon’s Communication Theory [Shannon 1948]), for example to exhort someone to do something or to express feelings or emotions. Not all of them are relevant in scientific research, constructed in particular around questions, proposal, rules, sentences [Bunge 1967: p.10]. Given that measurement has the role of bridge among realms, the role of language in it is specifically critical. Measurement can be intended in fact as a process aimed at conveying objective and inter-subjective information on empirical properties [Mari, Carbone, Petri 2012], and therefore the lack of ambiguity in the communication of measurement results [Price 2001] is a constitutive condition. This explains the interest in defining rules even for details such as for “writing unit symbols and names, and expressing the values of quantities”, a subject to

1 “Terminology work” is the title of a series of ISO standards to which we will refer in this paper. The interested reader is particularly invited to consult [ISO 704:2009] and [ISO 1087-1:2000].

2 The original title, “International vocabulary of basic and general terms in metrology”, has been changed in the third edition to “International Vocabulary of Metrology – Basic and general concepts and associated terms”, thus properly emphasizing the priority of concepts. “The title of the VIM Edition 3 [...] was changed from the title of the first and second editions of the VIM [...] in order to emphasize that a vocabulary is really more than a collection of terms, and is actually a collection of definitions that express concepts (in the case of the VIM, concepts pertaining to metrology), along with the commonly used terms that designate those concepts. Further, the concepts in the VIM Edition 3 are intended to form a concept system, wherein the concepts are, for the most part, not independent, but, rather, they are related to each other.” [Frequently Asked Questions (FAQs) on the VIM Edition 3 (VIM3), http://www.bipm.org/utils/common/documents/jcgm/VIM_FAQs.pdf].

which a whole section of the "SI Brochure" is devoted [BIPM 2006: p.130–135], with specifications such as "unit symbols are printed in roman (upright) type", or "a space is always used to separate the unit from the number". On the other hand, the topic of language of measurement spans much more than these low level, notational issues, and fully covers the semantic layer, where the issue is mutual understanding of concepts and therefore the target is to attribute shared and consistent meanings to technical terms used in scientific communication. And indeed is there always a mutual understanding when, e.g., the terms "calibration", "accuracy", "measurement results" are used? and what is a measurement model? and what does it distinguish measuring instruments and measuring systems? and what is the difference between sensitivity and resolution of an instrument?

Unfortunately, in metrology "there has sometimes been a tendency to promote [...] specialized terms and meanings as they produce an 'in-language', separating 'them' from 'us'. However ego-boosting this may be, it is not in the best interests of the accurate dissemination of scientific information." [Clifford 1985: p.72]. Measurement has a social prestige, witnessed by the significantly different information conveyed by "this is a measurement result" and "this is an opinion", even when both are expressed in quantitative terms. Such a difference cannot be a matter of the terms adopted in the measurement-related communication: calling "measure" an opinion is definitely not enough to make it more objective and inter-subjective. Rather, an appropriate answer to the previous questions, even if not required to become more skilled constructors or operators of measuring instruments, is critical to account for the peculiarity of measurement as knowledge-based process and to provide a justification for the resources devoted to measurement processes: the effectiveness of a bridge built among such different realms as the empirical world and the information world requires unambiguous language.

But considering that measurements are performed since millenia, is not it amazing that basic questions like those mentioned above are still an object of discussion? Is a possible "tendency to promote [...] specialized terms and meanings [that] produce an 'in-language'" sufficient to explain the situation? No, and there are at least two more general and important reasons explaining this situation.

First, precisely the well-grounded prestige of measurement, and the interest of constructively overcoming what has been called the "physics envy" or the "pretence of knowledge" [Myrdal, Hayek 1974], are pushing widespread attempts to extend the scope of measurability [Rossi 2007] so to include entities other than the physical quantities traditionally object of measurement: quantities or properties in the domain of chemistry, biology, medicine, psychology, sociology, economy, etc. This arises new problems, and a conservative position such as "if it is not a physical quantity then by definition it is not measurable" appears inadequate to societal requirements: in the multifaceted context of measurement "the watertight boundaries between the branches are fast disappearing, so it is essential that misunderstandings be prevented when they are caused by different people using the same term to mean different things, or by the use of a completely unfamiliar term." [Clifford 1985: p.72].

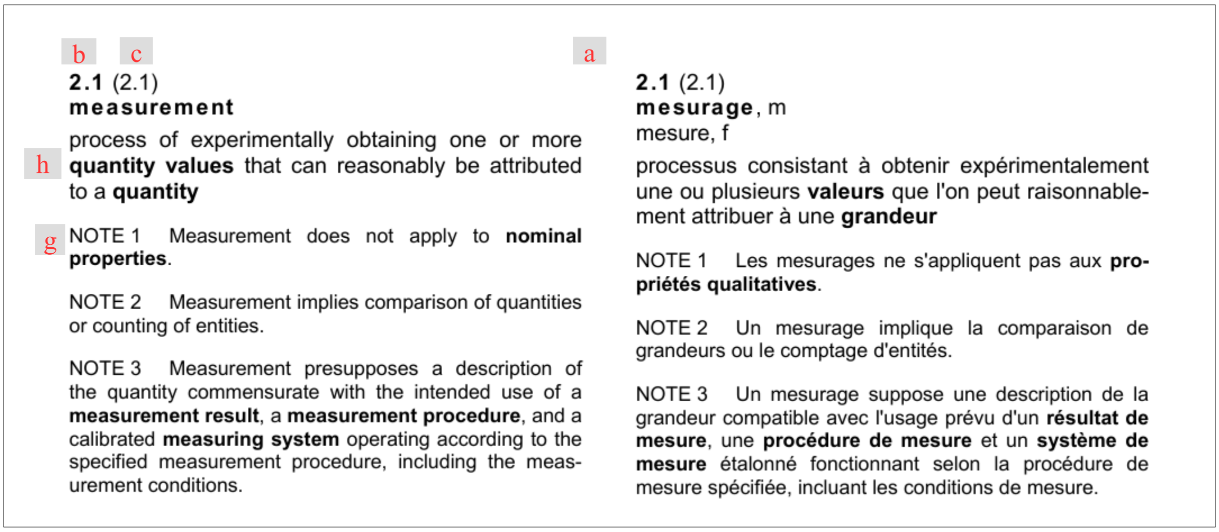
Second, a reason that might appear discouraging or even irritating to many and nevertheless it cannot be removed, measurement is a process so fundamental in its role of bridge among realms that unavoidably depends on pre-comprehensions about the nature of the empirical world and the knowledge of it. A critical and well-known example is about the concepts of error and uncertainty, relating to their mutual compatibility and with the delicate concept of true value of a quantity, such that “the change in the treatment of measurement uncertainty from an Error Approach (sometimes called Traditional Approach or True Value Approach) to an Uncertainty Approach necessitated reconsideration of some of the related concepts” [VIM3: Introduction], [Ehrlich 2014]. In the last decades several of these pre-comprehensions have changed (from verificationism, to falsificationism, to relativism, etc: this is not the context to develop further on philosophy of science as related to measurement; for an introduction see, e.g., [Mari 2003] and [Mari 2005]), and measurement science is still trying to elaborate a systematic position on these changes. In its role of “language of science”, measurement is particularly exposed to these changes, and therefore it is not so amazing in measurement science to observe terms with multiple and contrasting meanings (e.g., [Mari, Mencattini 2013] discusses the case of “sensitivity”, from the evidence that the International Electrotechnical Vocabulary (http://www.electropedia.org) lists several distinct meanings for it), a phenomenon called “polysemy” that produces ambiguous communication if not somehow corrected.

In this context “the four main international organizations which are concerned with metrology (BIPM, IEC, ISO and OIML) [decided] that there should be a joint action to produce a common terminology”, and their result was the *International vocabulary of basic and general terms in metrology* [ISO 1984 (VIM1)], published exactly thirty years ago. Since then two more editions of the VIM were released, in 1993 [ISO 1993 (VIM2)] and 2007 [JCGM 2012 (VIM3)], by a progressively extended inter-organizational committee that in 1997 formally was constituted as the Joint Committee for Guides in Metrology (JCGM). According to its Terms of reference, the JCGM works “to develop and maintain, at the international level, guidance documents addressing the general metrological needs of science and technology, and to consider arrangements for their dissemination” [JCGM Charter: 2]. The JCGM currently gathers eight international organizations and currently produces two guidance documents, the VIM and the *Guide to the expression of uncertainty in measurement* (GUM), both aimed “primarily at harmonizing worldwide current metrological practices and disseminating scientific and technological knowledge. They constitute recommendations that member organizations are strongly encouraged to implement.” [JCGM Charter: A.1.2]. The VIM is maintained and developed by JCGM-WG2 (http://www.bipm.org/en/committees/jc/jcgm/wg2.html).

3. The VIMs

Given the observation that in metrology “there has sometimes been a tendency to promote [...] specialized terms and meanings”, and with the hope to “stimulate dialogue between the experts of various specialized disciplines of science and technology, thus contributing to harmonized inter-disciplinary terminology” [VIM2: Foreword], the ambitious target of the VIM is “to be a common reference for scientists and engineers – including physicists, chemists, medical scientists – as well as for both teachers and practitioners involved in planning or performing measurements, irrespective of the level of measurement uncertainty and irrespective of the field of application. It is also meant to be a reference for governmental and inter-governmental bodies, trade associations, accreditation bodies, regulators, and professional societies.” [VIM3: Scope].

Such a “common reference” is therefore a vocabulary, having the structure of a list of entries, an example of which is as follows.



2.1 (2.1)
measurement

process of experimentally obtaining one or more **quantity values** that can reasonably be attributed to a **quantity**

NOTE 1 Measurement does not apply to **nominal properties**.

NOTE 2 Measurement implies comparison of quantities or counting of entities.

NOTE 3 Measurement presupposes a description of the quantity commensurate with the intended use of a **measurement result**, a **measurement procedure**, and a calibrated **measuring system** operating according to the specified measurement procedure, including the measurement conditions.

2.1 (2.1)
mesurage, m
mesure, f

processus consistant à obtenir expérimentalement une ou plusieurs **valeurs** que l'on peut raisonnablement attribuer à une **grandeur**

NOTE 1 Les mesurages ne s'appliquent pas aux **propriétés qualitatives**.

NOTE 2 Un mesurage implique la comparaison de grandeurs ou le comptage d'entités.

NOTE 3 Un mesurage suppose une description de la grandeur compatible avec l'usage prévu d'un **résultat de mesure**, une **procédure de mesure** et un **système de mesure** étalonné fonctionnant selon la procédure de mesure spécifiée, incluant les conditions de mesure.

Figure 1 – Example of an entry of the VIM [VIM3: 2.1]: (a) the text is bilingual, English and French (the VIM has been translated into a number of other languages, see http://www.bipm.org/en/publications/guides/vim.html); (b) entry identifier: chapter.sequence; (c) possible identifier of the corresponding entry in the previous edition of the VIM; (d) (preferred) term; (e) possible admitted terms, i.e., synonyms; (f) definition; (g) possible notes and examples; (h) bold texts in definition, notes, and examples refer to concepts defined in the VIM itself.
This structure is taken from [ISO 1087-1:2000], where the concepts 'term', 'definition', etc are defined.

Hence, the first hypothesis underlying this endeavor is:

H1. *A system of definitions of basic and general concepts of metrology and associated terms is useful for many classes of readers of different research and application fields*.

As linguistic infrastructures are convenient, if not mandatory, tools to support scientific and technological development, such a pragmatic hypothesis is hardly refusable. It is, for example, the reason that justifies the activities around the International Electrotechnical Vocabulary [IEC 60050], leading to observe the linguistic habits of the IEC Technical Committees and to collect the "terms and definitions" sections in the International Standards they produce. But in this context the VIM assumes a much more ambitious hypothesis:

H2. *The basic and general concepts of metrology can be consistently and unambiguously defined*.

Consistent and unambiguous definability and social usefulness are criteria for foundational, meta-scientific studies. According to [Bunge 1967: p.1], "the foundation of an empirical procedure recognized in science is the set of theories by means of which the procedure is designed, carried out, and interpreted. In every case, then, the foundations of a science are ultimately theoretical – yet neither self-sufficient nor eternal. The branch of scientific research concerned with setting up and scrutinizing such foundations is called *foundations research*". It might be then expected that consistent and unambiguous definitions are enablers, or at least facilitators, of scientific research.

The very existence of three editions of the VIM is a pragmatic proof that the organizations involved in their development believed that H1 and H2 are justified. On the other hand, in a situation of conceptual and lexical fragmentation the critical issue arises of how to choose among competing positions, so that socially acceptable definitions of the "basic and general concepts" of metrology can be formulated. A third hypothesis is then underlying the very idea of the VIM:

H3. *Unambiguous definitions of basic and general concepts of metrology can be given that are not "in conflict with [...] the actual state of our knowledge on the subject of metrology"* [VIM1: Foreword].

The methodology adopted to fulfill this challenging hypothesis is grounded on the principle of inter-organizational *consensus* [JCGM Charter: 7.1.5], as taken from the world of standardization: "general agreement, characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments." [ISO/IEC Guide 2:2004], where it is also noted that "consensus need not imply unanimity".[3]

The VIM3 is a product of the JCGM, thus published with the formal consensus of its eight international member organizations. A first draft of it "was released to the measurement community for public examination through relevant commissions of the patronizing organizations in 2004. More than 700 comments did receive an individual reply (accepted, covered, noted or rejected), and they contributed considerably to the improvement of the draft. The votes in 2006 were again accompanied by more than 100 comments and all of them were again considered." [De Bièvre 2007]. The relative novelty and the overall complexity of the JCGM structure (note that each member organization maintains its own procedures for information spreading and decision making) make it hard to reach any definitive conclusion about the significance of these data, and therefore the actual representativity of the outcome. On the other hand, the very existence of JCGM, and its WG2 in particular, witnesses that member organizations factually support a development process based on H1, H2, and H3. Moreover, the adoption of consensus as decision principle emphasizes the critical importance of the quantitative and qualitative composition of the group of "parties of the concerned interests" (the JCGM since 1997, its foundation year). The increase in number and the diversification in disciplinary field of involved organizations (see Table 1) is then a significant hint of the perceived growing importance of the VIM. The decision to make the pdf version of the VIM freely downloadable, taken by the JCGM in 2008, has been a further element supporting the endeavor "to enhance

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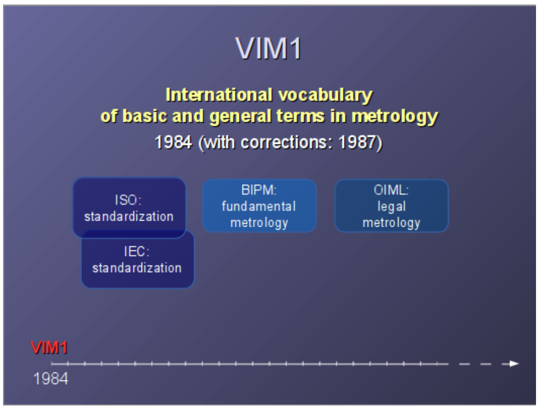
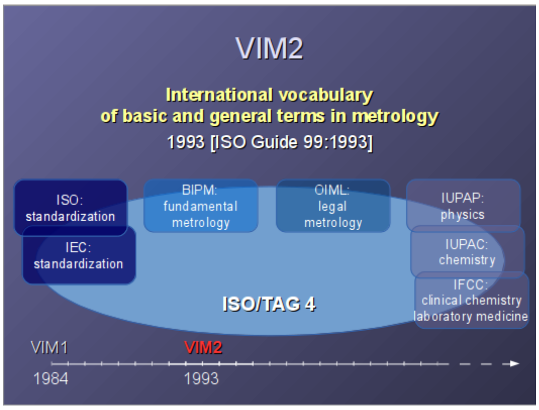
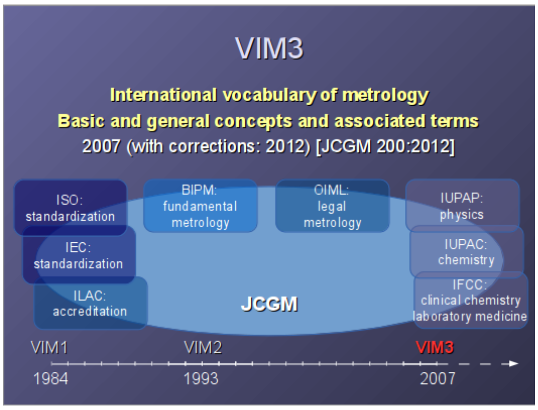
3 Consensus is a generic decision criterion, and as such it is not explicitly helpful in the construction stage of a concept system. On the other hand developing a system of "basic and general concepts" of metrology in compliance with the hypotheses H1-H3 is definitely a complex endeavor, and the fact that it is expected to be the outcome of the work of individual experts, appointed by the JCGM member organizations, where "expert(s) shall act in their personal capacity, contributing on the basis of their own knowledge" [JCGM Charter: 7.2.1], makes the identification of criteria supporting the construction process a relevant issue. According to the Author's view and experience, some construction criteria could be as follows.
Stability: any change to the current edition of the VIM should have a cogent justification.
Internal consistency: the VIM definitions should be coherent with each other (in other terms: no two definitions should contradict with each other).
External consistency: the VIM definitions should be coherent with the usage in the scientific and technical community.
Philosophical agnosticism: the VIM definitions should be formulated as independently of any philosophical position as it is possible.
Closure: all metrologically specific concepts referred to in one or more VIM definitions should be defined in the VIM itself.
Of course, not all these principles can be satisfied at the same time in all situations: in these cases consensus might require some compromises.

access to information about metrology” [VIM3: Disclaimer].

Table 1 – Some data on the three editions of the VIM.

<table>
<tr><td>Edition</td><td>Chapter structure [number of definitions in chapter]</td></tr>
<tr><td>
</td><td>1 Quantities and units [21]
2 Measurements [20]
3 Measurement results [15]
4 Measuring instruments [34]
5 Characteristics of measuring instruments [32]
6 Measurement standards [16]</td></tr>
<tr><td>
</td><td>1 Quantities and units [22]
2 Measurements [9]
3 Measurement results [16]
4 Measuring instruments [31]
5 Characteristics of measuring instruments [28]
6 Measurement standards, etalons [14]</td></tr>
<tr><td>
</td><td>1 Quantities and units [30]
2 Measurement [53]
3 Devices for measurement [12]
4 Properties of measuring devices [31]
5 Measurement standards (Etalons) [18]</td></tr>
</table>

4. Methodological issues in the development of a vocabulary of metrology

4.1. Definitions as knowledge tools

The VIM appears a loosely ordered collection of definitions, but is in fact a refined (even though not perfect, of course) *concept system* [ISO 1087-1:2000: 3.2.11], as can be expected from a foundational work. Definitions are usual devices in scientific and technical publications, but what a definition is and what is the role of definitions in knowledge construction and transmission is usually an overlooked subject, that in the present context deserves instead some attention.

First of all, “it will be useful for our purposes to distinguish clearly between *concepts* [...] and the corresponding *terms*, the verbal or symbolic expression that stand for those concepts” [Hempel 1966: 275], where concepts are “units of knowledge” [ISO 1087-1:2000: 3.2.1], that for being communicated, stored, processed, etc require indeed a linguistic form.[4] A usual source of confusion is whether what is defined are concepts or terms. In fact, "definitions are offered for one or the other of two quite different purposes: [one is] to assign, by stipulation, a special meaning to a given term which may be a newly coined verbal or symbolic expression (such as "pi-meson") or an "old" term that is to be used in a specific technical sense (e.g., the term "strangeness" as used in the theory of elementary particles). [These definitions] will be called *stipulative*. [The second possible purpose for a definition is] to state or describe the accepted meaning, or meanings, of a term already in use. [These definitions] will be called *descriptive*.".

Hence definable are either terms and concepts:

– on the one hand, "stipulative definitions [...] serve to introduce an expression that is used in some specific sense in the context of a discussion, or a theory, or the like", and therefore what they actually define are the terms that label the given units of knowledge";

– on the other hand, descriptive definitions "purport to analyze the accepted meaning of a term and to describe it with the help of other terms, whose meaning must be antecedently understood if the definition is to serve its purpose [, so that] they may be said to be more or less accurate, and even true or false." [Hempel 1966: 276].

VIM definitions are meant to be descriptive. When, for example, someone reads in the VIM3 "measurement: process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity", she is expected to have a previous knowledge of what a measurement is, so that such a definition operates as a clarification and specification tool for the concept. Compare it, indeed, with "qwertyuiop: process of experimentally obtaining...": while it can be intended as a stipulative definition, it is plausibly bound to generate a surprise exclamation: "but you are talking about measurement!".

Descriptive definitions (the only ones we will consider henceforth) are thus sophisticated devices involving relations among language, knowledge, and world:[5]

– on the one hand, knowledge aims at being knowledge of entities of the world: the concept 'measurement' is supposed to be about actual measurement processes;

– on the other hand, knowledge is managed by means of linguistic expressions: the concept 'measurement' is spelled out "measurement" in English and "mesurage" in French;

– finally, if knowledge is properly established and shared, then both the English "measurement" and the

4 That knowledge is not completely language-invariant, and therefore that "the structure and lexicon of one's language influences how one perceives and conceptualizes the world, and they do so in a systematic way" [Swoyer 2014], is a position called "linguistic relativity", and sometimes the "Sapir–Whorf hypothesis". As mentioned, the VIM text is bilingual, English and French: even in languages so similar as English and French some language-dependent differences can emerge. An interesting example comes in the VIM3 from the difficulty to express in French the concept 'magnitude', as in the definition of 'quantity':
– English: "property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference";
– French: "propriété d'un phénomène, d'un corps ou d'une substance, que l'on peut exprimer quantitativement sous forme d'un nombre et d'une référence".
Let us compare the structure of the two definitions:
– English: a quantity is a (i) property of X (ii) having a magnitude (iii) that can be expressed as Y;
– French: a quantity is a (i) property of X (ii) that can be quantitatively expressed as Y.
Hence, Y is the expression of a magnitude of a property in the English definition, and the expression of a property in the French one, hardly compatible positions.

5 We are adopting here a notational convention from ISO standards, e.g., [ISO 704:2009]: terms, and more generally linguistic expressions, are delimited by double quotes, concepts by single quotes, and entities of the world are not delimited. Hence, (the concept) 'measurement' is expressed in English by (the term) "measurement" and is about (the entity of the world) measurement. The lack of delimiters around terms for entities of the world follows an economic principle: when we write, we usually intend to refer to entities of the world, not concepts nor terms.

French “mesurage” designate actual measurement processes.

The relations among language, knowledge, and world, and more specifically among terms, concepts, and entities in the world, are effectively depicted in the so-called “triangle of reference”, or “semiotic triangle” [Ogden, Richards 1923].[6]

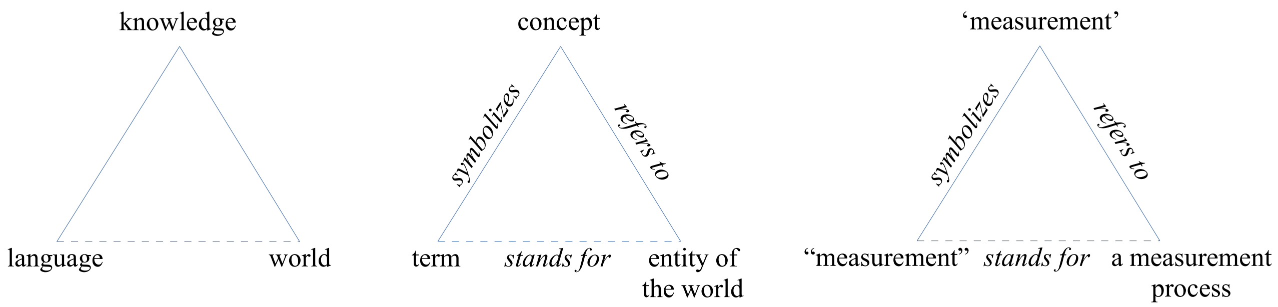


Figure 2 – The semiotic triangle, in the general (left) and the specific (mid) case, with an example (right). Adapted from [Ogden, Richards 1923: p.11].

4.2. Definitions as tools for building concept systems

In this framework, a definition can be understood as a device that produces knowledge by connecting concepts (hence specific semiotic triangles by their top vertexes), according to the principle that in the definition of a concept X the defining concepts $Y_1, ..., Y_n$ are supposed to establish conditions that are:

– *individually necessary*: each defining concept Y_i is required to define X, so that removing one or more would not define X but a more generic concept:

– *conjointly sufficient*: all defining concepts $Y_1, ..., Y_n$ together define X, and not a more specific concept.

The structure of descriptive definitions is then explicitly recursive: the concept X is defined by means of the concepts Y_i. This makes the construction of a concept system a critical process: how can an infinite regress be avoided? Three structural strategies can be in principle envisioned.

<u>A. Cross-definition</u>

The first is *cross-definition*, where concepts are directly or indirectly defined in reference to one another, and then the system grows from a bootstrap effect. This is the only option if all concepts in the system must be defined, a situation that is usually deemed as unavoidable in dictionaries of natural languages and allows their loose structure, but that is tentatively avoided in scientific and technical communication, where a more formal structure is expected.

<u>B. Bottom-up</u>

The second strategy is *bottom-up*: concepts referring to individual entities of the world are defined by means of some kind of direct reference (“‘kilogram’ is defined as the mass of that object”, uttered while indicating a given object, possibly maintained in Sèvres), and then other concepts are obtained by means of *extensional definitions* [ISO 1087-1:2000: 3.3.3], that list the possible cases of the concept under definition according to

6 This subject is so fundamental that, not so amazingly, the related terminology is not standardized; for example, instead of “term, concept, entity in the world” [Ogden, Richards 1923] use “word, thought, thing” and [Bunge 1974: p.XI] “symbol, construct, fact”, whereas [ISO 1087-1:2000] uses “designation, concept, object”. For a more extended presentation for the semiotic triangle in the context of metrology, see [Dybkaer 2004].

a *disjunctive logic*: X: Y_1 or ... or Y_n, i.e., *the specifics defines the generic* (the example of an extensional definition for 'base quantity in the International System of Quantities' might be "length, mass, time, electric current, thermodynamic temperature, amount of substance, luminous intensity", provided that 'length', 'mass', etc have been already somehow defined). This strategy is attractive for its limited theoretical burden, that gives it an empiricist flavor, but is applicable only in finite domains where explicit listings can exhaust all cases of a concept. Of course, this is not the case of metrology.

C. Top-down

What remains is the last strategy, the one followed by the VIM. It is *top-down*: some generic concepts are assumed without a definition – they are called "primitives" – and from them other concepts are subsequently obtained according to a *conjunctive logic*: X: Y_1 and ... and Y_n, i.e., *the generics defines the specific*. For example, the VIM3 definition of 'measurement' ("process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity") can be understood as a nice rephrasing of: measurement (X) is a process (Y_1) and (the process) is an experimental obtainment of values (Y_2) and is a reasonable attribution of (these) values to a quantity (Y_3). Evidently, for such a definition to be well formulated the defining concepts in it ('process', 'experimental obtainment of values', 'reasonable attribution of values to a quantity') must be predefined.

This analysis, that could be repeated for all the definitions of the VIM, shows that the selection of the primitive concepts for the VIM is a critical decision: they should be simple enough to be unambiguously understood by everyone or however extra-metrological, under the assumption that all metrologically-relevant (basic and general) concepts are instead defined in the VIM itself ("in this Vocabulary, such non-defined concepts include: system, component, phenomenon, body, substance, property, reference, experiment, examination, magnitude, material, device, and signal" [VIM3: Terminology rules]).

In a concept system built according to this top-down strategy *definitions are specification means*: through definitions the system is built by progressive knowledge specification, where the relation between the defined concept X and each of the defining concepts Y_i is then species-genus, i.e., subtype-supertype, or, according to the ISO standards on terminology work, subordinate-superordinate (hence the VIM3 defines 'measurement' as a species / subtype / subordinate of the genus / supertype / superordinate 'process'). Furthermore, concept systems are appropriately structured through *intensional definitions* [ISO 1087-1:2000: 3.3.2], in which one defining concept Y_1 is singled out as *the* superordinate, the remaining Y_2, ..., Y_n being its "delimiting characteristics" [ISO 1087-1:2000: 3.2.7]. This leads to the template:

defined concept : *superordinate concept* such that *delimiting characteristics*

that can be read "X is a Y_1 such that Y_2 and ... and Y_n", e.g., a measurement is a process such that it is an experimental obtainment of values and is a reasonable attribution of these values to a quantity. The VIMs have been constructed more or less strictly following this structure: "definitions shall include the superordinate concept immediately above, followed by the delimiting characteristic(s). The superordinate concept situates the concept in its proper context in the concept system." [ISO 704:2009: 6.2].[7] A concept system built in compliance with this template is strictly hierarchical, with each child (subordinate) concept having only one father (superordinate) concept, and all concepts without fathers – at least one of them must be included in the system – are primitives.[8]

5. Some important changes in the contents of the VIMs

In Section 2 a general justification has been already proposed of the three editions of the VIM in thirty years: metrology is a moving target, and the VIMs have tried to track it. Since only "basic and general concepts" are defined in the VIM, the changes that are found in comparing the VIM1 and the VIM3 have nothing to do with technological changes, despite, e.g., in 1984 nothing comparable to the world wide web or the smartphones was available. Rather, the changes are mainly conceptual: with some simplifications, the VIM1 can be intended as representative of a *traditional standpoint* on measurement, and the VIM3 as the result of the current understanding of measurement itself according to a *new standpoint*, that tries to overcome some flaws of the traditional one. This interpretation is schematically proposed here in reference to three fundamental questions:

– what is measurable?

– what is measured?

– what is measurement?

5.1. What is measurable?

The traditional standpoint can be stated as: *measurability is a feature of empirical properties that can be compared with each other in terms of their ratio*. The VIM1 adopts this standpoint and presents it in reference to *quantities*, by assuming that:

– quantities are specific properties ('quantity' is defined as "an attribute of a phenomenon, body or substance, which may be distinguished qualitatively and determined quantitatively" [VIM1: 1.01], where "attribute" and "property" can be considered as synonyms);

– only quantities, and not more generic properties, are measurable ('measurement' is defined as "the set of operations having the object of determining the value of a quantity" [VIM1: 2.01]).

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7 The subordinate-superordinate relation expressed by "X is a Y" is the fundamental building block of a concept system, but unfortunately the relation *is-a* has (at least) two distinct meanings, *is-subtype-of* and *is-instance-of*. Consider, for example:
1. a material measure *is-a* measuring instrument: this means that the concept 'material measure' is a specification of the concept 'measuring instrument'; this is a *concept-concept relation*;
2. the International Prototype of the Kilogram *is-a* measurement standard: this means that the object IPK is an example of the concept 'measurement standard', i.e., an instance of it; this is an *object-concept relation*.
While systems such as NIST' UnitsDB, "containing detailed information on scientific units of measure" based on the XML markup language UnitsML (http://unitsml.nist.gov), are aimed at being databases populated of objects / instances, the VIM can be intended as the hierarchical structure of an empty database.

8 There is nothing necessary in this single inheritance pattern, and in fact the alternative single vs multiple inheritance (e.g., in object-oriented programming languages Java vs C++) is an open-ended discussion. Single inheritance leads to much simpler tree-like (instead of directed graph) structures. The VIM3 definitions are intensional, and then follow the single inheritance pattern, with a few interesting exceptions, in particular:
– 'quantity value' is defined as "number and reference together expressing magnitude of a quantity" [VIM3: 1.19] (more than a single superordinate, 'number and reference' appears to be the conjunction of two concepts);
– 'metrology' is defined as "science of measurement and its application" [VIM3: 2.2].
This does not enable to specify "a quantity value is a Y" and "metrology is a Y", where Y is a single concept. The second case seems to be easily solved, for example by rephrasing "body of knowledge that includes the science of measurement and its applications", thus acknowledging metrology as a body of knowledge. The first case is instead delicate, and the VIM3 definition seems to suggest the lack of general agreement about what quantity values are [Mari, Giordani 2012].

The VIM3 maintains the VIM1 assumptions, but weakens their extent by implicitly redefining the concept ‘quantity’ so that also the properties comparable by order, and not only by ratio, are considered quantities. The concept ‘ordinal quantity’ is defined thus as “quantity, defined by a conventional measurement procedure, for which a total ordering relation can be established, according to magnitude, with other quantities of the same kind, but for which no algebraic operations among those quantities exist” [VIM3: 1.26]. This move is consistently complemented by the redefinition of ‘quantity value’, from “number and unit” [VIM1: 1.17] to the more generic “number and reference” [VIM3: 1.19], and is justified with the role assumed for magnitudes: according to the VIM3 quantities are properties that “have a magnitude” [VIM3: 1.1], so that the primitives ‘to have magnitude’ and ‘to be measurable’ seem to be used here as coextensive (note that in the VIM1 the concept ‘magnitude’ did not appear at all).

5.2. What is measured?

The traditional standpoint can be stated as: *measurement conveys uninterpreted information on the empirical property in input to the measuring instrument*. The VIM1 adopts this standpoint and presents it in reference to *measurands*, by assuming that:

– measurement is aimed at “determining the value” [VIM1: 2.01] of a measurand;

– a measurand is a “quantity subjected to measurement” [VIM1: 2.09].

The VIM3 redefines ‘measurand’ as a “quantity intended to be measured” [VIM3: 2.3]. This reference to intentions has nothing to do with psychological issues. The change can be understood by considering the basic fact of measurement that its result is reported as “quantity = value” (uncertainty can be neglected here), and asking: what is this reported quantity? The VIM1 seems to imply that it is the quantity with which the measuring system interacted in the experimental stage of measurement (the “quantity subjected to measurement”), an option that is attractive for its lack of theoretical assumptions[9] but that hinders the transferability of the information due to its explicit dependence on the measuring system. Rather, the quantity should be reported as “the quantity of the object... in the conditions...”, i.e., it should be defined in a measurement independent way. Of course, the idea is that the measurer is expected to do her best to let the measuring system interact with the quantity she intends to measure, so that the quantity subjected to measurement and the quantity intended to be measured are the same, but the measurement result is to be attributed to the quantity that has been defined, not to the (unknown) quantity with which the instrument actually interacted. Hence, with the new definition of ‘measurand’ the VIM3 has emphasized that measurement is not a purely experimental process, as instead traditionally intended, and that models play an unavoidable, critical role in it.

5.3. What is measurement?

The traditional standpoint can be stated as: *measurement is a purely experimental process*. The VIM1 adopts this standpoint and presents it in reference to *measurement*, by assuming that:

– measurement is a determination process;

9 This position has indeed a strong operationalistic flavor: “The concept of length is fixed when the operations by which length is measured are fixed: that is, the concept of length involves as much as and nothing more than the set of operations by which length is determined.” [Bridgman 1927: p.5].

– the measurand has a single value, that measurement aims at determining.

The VIM3 redefines ‘measurement’ as a “process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity” [VIM3: 2.1], where the difference is then from “determining the value” to “reasonably attributing one or more values”. The apparent change, from one value to one or more values, is understood in terms of the perhaps less manifest change, from determination to attribution: for being determined an entity must preexist, a condition that is not imposed to an entity that is attributed, or assigned [Mari 1997]. The new standpoint is then less demanding: it could accept that values “exist in” quantities independently of measurement, but it does not require it. It emphasizes that measurement is not (only) a discovery but (also) an invention, due, once again, to the unavoidable adoption of models. This explains the noncommittal condition “one or more values” (a model could provide different outputs, from single values to probability distributions of them), and the reference to “reasonableness” of attribution, to be intended as an appropriate (in a sense to be specified) choice of models.

6. Conclusions

“All branches of science and technology need to choose their vocabulary with care. Each term must have the same meaning for all of its users; it must therefore at the same time express a well-defined concept and not be in conflict with everyday language.” [VIM1: Foreword]. This programmatic sentence marks the beginning of the history of the International Vocabulary of Metrology and captures the main challenge its development puts forward: producing a system of “basic and general concepts and associated terms” of metrology that is internally consistent and socially acceptable. The evolutionary situation of metrology makes the required harmonization process complex and full of threats, given the need to guarantee both correctness, despite the lack of a widespread consistent language of metrology, and understandability, despite the lack of a homogeneous cultural background of metrology.

Which pre-competences can be assumed in the “average reader” is indeed a critical problem for the positive acceptance of an international vocabulary, and it is so particularly towards a future fourth edition of the VIM: probability theory and statistics? signal theory? computer science? formal logic? set theory and algebra? ... The fact that metrology is more the confluence of several scientific and technological fields than a monolithic discipline generates the interesting side effect that different metrologists might share only a limited fraction of their concept and lexical systems, a situation that can be observed also in the diachronic perspective of the three editions of the VIM, that in a relatively short interval of time have changed the meaning of such fundamental concepts as ‘quantity’, ‘measurand’, and ‘measurement’ (so that one might even write, e.g., “VIM1-quantity”, “VIM2-quantity”, and “VIM3-quantity”, then claiming that ‘VIM1-quantity’ ≠ ‘VIM3-quantity’). This highlights the importance of developing a comprehensive well-structured *metrology body of knowledge* (possibly building on collective works such as [Sydenham, Thorn 2005]), in which an international vocabulary of basic and general concepts and associated terms would play an important role.

Acknowledgments

This paper has been significantly improved as the result of several discussions with Charles Ehrlich: thank

you Chuck.

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