Some reflections on what is measurement - and what it is not

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Abstract

The concept of measurement is central to both physical and social sciences, as it is intimately related to the experimental acquisition and validation of knowledge. However, measurement is commonly considered a critical but only instrumental process, which provides “the correct assignment of numbers to physical variables” (Chang, Cartwright 2008) and that connects “reason to Nature” (Margenau 1958). Regrettably, despite its long history, measurement is laden with stereotypes rooted in outdated conceptions of the physical world, which hinder its theoretical advancement and practical contribution. Moreover, the adoption of measurement in very diverse fields has resulted in context-dependent, ambiguous terminology (e.g., “quantity”, “accuracy”, “scale”) that makes interdisciplinary communication and collaboration on measurement related topics difficult.

This seminar will start by presenting a brief history of measurement and will then discuss the following:

• what is measurement and why is it so important?
• how is measurement different from opinion and generic evaluation?
• how can we decide whether measurement results are acceptable?
• what are the effects of measurement on what is being measured?
• can measurement be defined and used in the same way for both physical and non-physical properties?
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He is currently the chairman of the TC1 (Terminology) and the secretary of the TC25 (Quantities and Units) of the International Electrotechnical Commission (IEC), and an IEC expert in the WG2 (VIM) of the Joint Committee for Guides in Metrology (JCGM). He has been the chairman of the TC7 (Measurement Science) of the International Measurement Confederation (IMEKO). He is the author or coauthor of several scientific papers published in international journals and international conference proceedings. His research interests include measurement science and system theory.
Some of my recent publications


LM, **Evolution of 30 years of the International Vocabulary of Metrology (VIM)**, *Metrologia*, 2015


LM, **A quest for the definition of measurement**, *Measurement*, 2013

LM, A.Giordani, **Quantity and quantity value**, *Metrologia*, 2012


A.Giordani, LM, **Property evaluation types**, *Measurement*, 2012


A.Frigerio, A.Giordani, LM, **Outline of a general model of measurement**, *Synthese*, 2010

A customary opinion

number of open fundamental problems of measurement

Consequence:

never argue with an engineer if you are interested in fundamental problems of measurement

Correct?
A basic question

What is the difference between measurement and opinion?

Lexical note:

- “measurement”: the process (a *nomen actionis*)
- “measurement result”: the result (a *nomen rei actae*)
The different interpretations on the scientific role of measurement shed some light on the different interpretations of what measurement is.

«Our most prevalent notions both about the function of measurement and about the source of its special efficacy are derived largely from myth»

[Kuhn 1961]
The traditional interpretation of the role of measurement

According to the Euclid’s Elements, Book V,
– sometimes intended as “the earliest contribution to the philosophy of measurement available in the historical record” [Michell 2005] –
«a magnitude is a part of a(nother) magnitude, the lesser of the greater, when it measures the greater»

Measurement is a (the?) tool to obtain quantitative information
The traditional interpretation of the scientific role of measurement

«[Newton’s mechanics] was a deductive science, exactly like geometry. Yet Newton himself asserted that he had wrested its functional principles from experience by induction. In other words, Newton asserted that the truth of his theory could be logically derived from the truth of certain observation-statements.»

[Popper 1962]

Measurement is a (the?) tool to obtain true observation-statements
true values of quantities
Falsificationism

«Theories cannot be logically derived from observations. They can, however, clash with observations: they can contradict observations. This fact makes it possible to infer from observations that a theory is false. **The possibility of refuting theories by observations is the basis of all empirical tests.»**

[Popper 1962]

«The results in the table seem to function as a test of theory. If corresponding numbers in the two columns agree, the theory is acceptable; if they do not, the theory must be modified or rejected.»

[Kuhn 1961]
Falsificationism

Given the emphasis on theories and their epistemic role, falsificationism seems to be less interested in “observations”:

measurement results can be still taken for granted...

This position does not imply a re-interpretation of the scientific role of measurement
Constructivism

«Seeing is a “theory-laden” undertaking: observation of x is shaped by prior knowledge of x»

[Hanson 1958]

... so that «pure or neutral observation-languages» do not exist

[Kuhn 1962]

«Although conception without perception is merely empty, perception without conception is blind (totally inoperative). [...] With false hope of a firm foundation gone, with the world displaced by worlds that are but versions, with substance dissolved into function, and with the given acknowledged as taken, we face the questions how worlds are made, tested, and known.»

[Goodman 1978]
If «anything holds» (including cheating about experimental results) [Feyerabend 1975], what does it remain of the claimed “special efficacy” of measurement?

How is measurement different from opinion, judgment by experience, guess, … then?

… maybe it is because quantification, as in Euclidean geometry?
Measurement is not quantification

Euclid’s Elements:

«a magnitude
is a part of a(nother)
magnitude,
the lesser of the greater,
when it measures the greater»

«a number
is a part of a(nother)
number,
the lesser of the greater,
when it measures the greater»

and in fact, throughout the Elements, ‘measurement’ is never used, since «in the geometrical constructions employed in the Elements empirical proofs by means of measurement are strictly forbidden»

(from the introductory notes of [Euclid])

Do not consider “measure” and “measurement” as synonymous!

see also [Bunge 1973]
claim: measurement ≠ opinion

why?

traditional position:

truth

quantification

falsificationism

constructivism

???

Measurement DOES remain different from opinion: but how?
The default position for PHYSICAL properties is, more or less:

- measurement is a process performed
- by a properly designed, setup, and operated measuring instrument,
- based on a sensor able to interact
- with the property under measurement

This is maybe ok, but does not apply for NON-PHYSICAL properties

Here appear the so-called “representational theories of measurement”
Measurement is any process producing information that preserves empirical relations ("measurement as morphic representation")

(see, e.g., the monumental [Krantz et al 1971, 1989, 1990])

This is a reasonable necessary condition, but hardly sufficient
(it neglects things such as measurement standards, instrument calibration, metrological traceability, ...)

Representational theories of measurement
What is measurement then?

Experimental conditions

- Yes
  - 4. ???
  - 2. Galileo

- No
  - 3. Stevens
  - 1. Euclid

Algebraic conditions

- No
- Yes
A proposal

Measurement is a process that delivers information, as values of properties, that is:

- specifically related to the measurand and not to some other properties of the object under measurement or the empirical environment, which includes also the subject who is measuring → it is a condition of object-relatedness, i.e., of objectivity

- univocally interpretable by different users in different places and times, thus implying that a measurement result has to be unambiguous and unambiguously expressed → it is a condition of subject-transparency, i.e., of intersubjectivity

(see, e.g., [Mari et al 2012])
Measurement
and measuring systems

When measuring a physical property, these conditions are guaranteed by the measurement system itself:

- the output of the measuring instrument ideally depends only on the property under measurement, and it is independent of all other properties of the empirical environment → **this confers objectivity to the provided information**

- the measuring instrument is calibrated against a measurement standard, thus making measurement results traceable so that different measuring instruments calibrated within the same metrological system provide compatible information → **this confers intersubjectivity to the provided information**
The structure of measurement

- **Objectivity context**
  - Environment
  - System under measurement
  - Measurand
  - Other properties

- **Intersubjectivity context**
  - Measurement standard
  - Measuring system
  - Measurement unit
  - Measurement result

- Other properties
Realistic situation

- environment
  - system under measurement
    - measurand
    - other properties
  - other properties

- measuring system
  - measurement
    - standard
    - measurement unit
  - measurement result
For physical quantities there is a long, well-established tradition about how to design, set up, and operate this system in order to maintain non-objectivities and non-intersubjectivities at an acceptable degree.

What about non-physical quantities?
A R&D programme

experimental conditions

yes

no

how to structurally obtain objectivity and intersubjectivity even without physical sensors?

algebraic conditions

no

yes
A structural framework

Measurement is a complex model-based goal-driven process

Multiple activities performed (some implicitly) can be organized in a structural framework inspired to both:

- the well-known Deming cycle (Plan-Do-Check-Act) and
- models used to represent product development processes in manufacturing or software engineering

In PDCA (and in FraMeD):

- tasks are executed according to a loose ordered sequence
- feedback is needed to refine activities until requirements are met
FraMeD interprets measurement as a three-level hierarchically structured process:

- comprising stages,
- each one composed of activities,
- performed through multiple tasks

(see [Petri et al 2015])
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<th>Stages</th>
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FraMeD: an overview

- FraMeD: FraMeD
- Stages: planning, execution, interpretation
- Activities: goal setting, setup, data acquisition, information extraction and reporting, decision, learning

- Modeling
- Data acquisition
- Information extraction and reporting
- Decision
- Learning
FraMeD: an overview

A framework such as FraMeD is useful for:
- discussing on concepts and identifying conceptual or operative issues in a shared context and with a shared vocabulary
- providing an analytical modeling approach even when math is not applicable
- encourage a structured methodology in designing and performing measurements
The empirical task of data acquisition is necessary to measurement, but measurement is much more than just an empirical task.

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Thank you for your kind attention

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References

M.Bunge, On confusing ‘Measure’ with ‘Measurement’ in the methodology of behavioral science, in: The methodological unity of science, M.Bunge (ed.), 1973

P.Feyerabend, Against method: Outline of an anarchistic theory of knowledge, 1975

H.N.Goodman, Ways of worldmaking, 1978

N.R.Hanson, Patterns of discovery: An inquiry into the conceptual foundations of science, 1958


T.S.Kuhn, The function of measurement in modern physical science, Isis, 1961

T.S.Kuhn, The structure of scientific revolutions, 1962


J.Michell, The logic of measurement: A realist overview, Measurement, 2005
