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Measuring measurement – What is metrology and why does it matter?

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ABSTRACT

Metrology remains a uniquely important endeavour. A sign of its success and robustness as an infra-technology is that it usually goes unnoticed. This means that it is in danger of being under-valued and under-appreciated. The sure-footing that metrology provides to the quality infrastructure will be especially important as the world grapples with the aftereffects of the COVID-19 pandemic, rebuilding global economies and also re-focusing on addressing global grand challenges and exploiting emerging technologies. In this context it is important and timely to re-examine the concept of metrology and how it relates to the quality infrastructure that it serves, but differs to measurement in general. The concept of metrology as 'measuring measurement' is proposed, emphasising the characteristic meta-thought associated with the discipline that distinguishes it from routine measurement.

1. Introduction

The International Bureau of Weight and Measures states that: "Metrology is the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology." [1] Metrology is surely at the core of all practical scientific endeavours. Metrology is important because almost all of everyday life, not to mention practical science, technology, engineering and medicine, involves measurements that we rely on for our health, commercial prosperity, quality of life and the protection of the environment. Metrology is the structure that ensures these measurements are stable, comparable and accurate, providing confidence in measurement at a stated level (usually by quoting a measurement uncertainty). When these qualities are associated with a measurement it reduces waste, allows trade, enables infrastructure to function, technology to advance, the economy to prosper, encourages global agreement, collaboration and trade, and ensures our ongoing health and safety and quality of life. In short, metrology generates systems and frameworks for quantification and through these underpins consistency and assurance in all measurement. However, metrology, by most definitions, remains a very small endeavour compared to all the activities that rely on it. It is worth exploring this distinction in more detail.

2. Discussion

It is clear from its definition that the reach of metrology is far and wide. However, the term is not widely used or known. This is because metrology is an infra-technology. In the same way that infrastructures support society in general, infra-technologies support the operation of scientific and technical goals. If the making of measurements and exchange of measurement results is like traffic, then metrology is like the road network: a fundamental part of the system allowing for smooth and seamless operation of the whole. When working well it is unnoticed: when potholes appear on the road, we notice.

'Measurement space' in science and technology is huge – it is difficult to conceive of any scientific, technological, engineering or medical endeavour that doesn't rely on measurement – but the part of this that is formally metrology is small. All of metrology may be considered as a subset of measurement, but not all of measurement is metrology – not by a long way. Even though many of the fundamental concepts of good measurement and metrology are similar – traceability, comparison and uncertainty – the vast majority of measurement sits outside metrology. Metrology, as the 'science of measurement' implies a meta-subject with a deeper level of abstraction. Metrology might be thought of as 'meta-measurement', that is: 'measurement' operating at a higher level in order to elaborate the properties of 'normal' measurement. (In the same way, in linguistics, grammar is considered as a metalanguage used to describe the properties of plain language but not itself.) To generalise, in the same way philosophy is known popularly as 'thinking about thinking' so we can consider metrology as 'measuring measurement'.

Better measurement improves understanding of science and technology. Better metrology improves understanding of measurement.

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Improvements in science and technology enable advances in metrology. This is the virtuous circle that drives human development. By measurement, 'good measurement' is meant. That is: measurement exhibiting the qualities of stability, comparability (and coherence if traceable to the SI), with demonstrable, fit-for-purpose accuracy and a statement of uncertainty in the measurement values produced, under the control of a local quality system, and within the broader remit of a national quality infrastructure providing universal confidence in measurement. By contrast, poor measurement, not exhibiting these qualities, is not useful in advancing science.

Rather like most definitions there is no sharp delineation between what is measurement and what constitutes metrology. It is part of the same continuum ensuring confidence in measurement. We can consider work that is unique to the role of National Metrology Institutes (NMIs) and Designated Institutes (DIs) as clearly metrology. These activities are:

- the definition and realisation of measurement units (note that these need not be SI units, but must be the highest point of reference nationally);
- the maintenance, development and improvement of these primary national standards and realisations, and;
- the dissemination of traceability and traceable measurement directly resulting from these primary standard realisations.

This is considered as 'scientific metrology' (or sometimes 'fundamental metrology') – in particular these are areas where global agreement is required [2]. We may also consider as metrology work to measure fundamental constants (often done in collaboration with university-based academics and occasionally by academics alone, for instance in measurement of big G in [3]).

Assuring confidence in measurement results via certification, standardization, accreditation and calibration, often known as 'industrial metrology' [2] (since that is the sector where it is usually found) or 'applied metrology' may to a lesser extent be considered as containing aspects of metrology, but may also just be 'good measurement'. The degree to which these areas can be considered metrology depends on the extent of meta-study and meta-thought that is involved at each step. For example, calibrating an instrument is not in and of itself metrology unless extra detailed thought is applied, for example: original contributions to the calculation and propagation of uncertainty of the measurement. It is clear that maintaining quality assured, accredited measurement capability requires significant care and skill, but this doesn't necessarily involve the detailed meta-thought and analysis required of metrology. Good measurement may still be routine measurement – there is nothing wrong with that.

Legal metrology [2] exists to deal with the application of the law to metrology and regulated measurement. In many ways it can be considered as infrastructural but at a more applied science level that the infra-technology of scientific metrology, often with local implementation depending on national jurisdiction. To extend the analogy above: if scientific metrology is the road network and measurement is traffic flow then legal metrology is the road signs, speed limits and traffic lights. Legal metrology has an important part to play in better regulation (in the analogy: keeping the traffic moving smoothly and safely and without congestion).

Meta-thought is more obvious and more concentrated in the activities of primary metrology at the top of the quality infrastructure. The metrology component becomes less clear and obvious and more disperse as one descends the, nonetheless essential, quality infrastructure components of accreditation, standardisation, conformity assessment and market surveillance [4]. By the time end user measurements are made, be they in the factory or in the field, the data produced is usually the endpoint in the traceability chain, and the mechanism of production is much more rarely subject to additional meta-thought. Indeed, in the majority of cases, measurement is not metrology, even good measurement. In particular, making measurements with no associated meta-thought is not metrology. Nor is metrology necessarily concerned with research into new measurement techniques, new instruments, applied science, curiosity driven research or discovery science, unless there is any associated or subsequent meta-thought, meta-study, or a clear linkage of these activities back to provision of primary standards or realisation of measurement units.

3. Conclusion

The world needs good measurement more than ever to ensure sustainable progress in science and in society. Good measurement enables societal progress and economic growth via an agreed quality infrastructure. Metrology sits at the top of this quality infrastructure providing the stable definitions of measurement units and realisation of primary standards for these, from which traceability chains can flow; and improving these realisations to continue to reduce uncertainties for the end user. Because of this underpinning, infrastructural characteristic, metrology and its role in the quality infrastructure often goes unnoticed, and its distinction from measurement can become blurred. Metrology is distinguished from other quality infrastructure components as it is based almost entirely on meta-thought and meta-measurement – 'measuring measurement' – a concept that is necessarily decreasingly present as one descends the quality infrastructure and traceability chain. Good measurement is necessary to make progress in science but not on its own sufficient without metrology accompanying it. A joined-up measurement infrastructure and quality system [5]:

- Improves effectiveness of research and development and the trust in its outcomes;
- Improves efficiency, reducing waste and increasing productivity;
- Accelerates innovation, getting products to market faster, or allowing them to fail fast;
- Enables change to happen faster, adding value to society;
- Is essential for the development and assessment of evidence-based policy.

The world needs to realise these benefits now in order to address the challenges of COVID-19, stimulate economic recovery and return to facing global grand challenges such as: climate change, clean growth, achieving net zero carbon emissions by 2050, and an ageing population; and to exploiting emerging technologies such as: big data and the digital world, artificial intelligence, quantum technologies, industry 4.0, future communications and personalised medicine. These benefits of good measurement are particularly relevant for areas that don't currently embrace the quality infrastructure, such as much of the academic sector and many small and medium-sized enterprises [6,7].

We should celebrate metrology and the role it plays in keeping the measurement highway free of potholes, and better promote its benefits together with those of a joined-up quality infrastructure.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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