XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

REALISTS' VS. INSTRUMENTALISTS' UNDERSTANDING OF MEASUREMENT

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Abstract – The main idea of this paper is to analyse the consequences of the philosophical stance – and in particular of the understanding of truth underlying that stance – for the every-day language of measurement science.

Keywords: measurement science, philosophy of science, realism and instrumentalism.

1. INTRODUCTION

It is a generally-accepted conviction that the results of observation and measurement provide a reliable evidence for a scientific theory: although they cannot prove that it is correct, they can refute it. Therefore, measurement is widely considered as the most reliable source of information on physical reality. Students of engineering are taught that neither mathematical models of physical objects may be designed nor corresponding theories may be verified without measurement. This simplistic view is a very convenient starting point for teaching applications of measurement in engineering, but it cannot withstand criticism resulting from thorough logical analysis of the epistemological status of measurement. The following statements [1] explain the source of difficulties:

– Any procedure of mathematical model identification may be decomposed into two qualitatively different stages: identification of the structure of the model and identification (estimation) of its parameters. The interpretation of the concept of measurement in terms of homomorphism implies the conclusion that the measurement may be considered as a special case of parameter identification.
– The credibility of a mathematical model depends on the credibility of measurements used for its verification or validation. On the other hand, the credibility of those measurements depends on the credibility of mathematical models used for designing measurement instruments.
– Consequently, epistemological status of measurement and mathematical modelling must be considered comparable. The answer to the question about the relation of measurement results and mathematical models to physical *reality* remains open until axioms of gnoseology are introduced into play.

The above-sketched way of reasoning seems to complicate a widely-accepted picture of measurement-based sciences, but at the same time it may significantly enhance the discussion on the fundamentals of measurement science, including the definitions of key concepts that interdiscipline relays upon. In a more practical dimension, it may also contribute to better understanding of weakly-defined and virtual measurements, and accelerate their integration with traditional measurement science.

The main idea of this paper is to analyse the consequences of the epistemological stance or more precisely – of the definition of truth underlying that stance – for the every-day language of measurement science.

2. EPISTEMOLOGY, CONCEPTS OF TRUTH, AND METHODOLOGY OF SCIENCE

Epistemology is a chapter of philosophy that addresses the philosophical problems concerning knowledge and related concepts, in particular – the degree to which it is certain, and the relation between the subject acquiring knowledge and the object of knowledge [2].

In the early years of the XXth century, special attention was given to the relation between the act of perceiving something, the object directly perceived, and the result of the perception. The phenomenalists contended that the object of knowledge is the same as the object perceived. They attempted to clarify the relation between the act of knowing and the object known, and proposed cognitive procedures by which one would be able to distinguish the way things appear to be from the way one thinks they really are. The neo-realists argued that one has direct perceptions of physical objects or parts of physical objects, rather than of one's own mental states. The critical realists took a middle position, holding that although one perceives only sensory data such as colours and sounds, these stand for physical objects of which they provide knowledge.

During the second quarter of the XXth century, two schools of thought emerged, *viz.*: logical empiricism and linguistic philosophy. The logical empiricism (called also logical positivism) insisted that there is only one kind of knowledge, *viz.*: scientific knowledge; that any meaningful knowledge claim must be verifiable in experience; and hence that much of what had passed for philosophy was neither true nor false but simply meaningless. Most linguistic philosophers agree that the proper activity of philosophy is clarifying concepts in order to settle philosophical disputes and resolve philosophical problems which – most frequently – originate in linguistic confusion. Consequently, they examine the actual way such epistemological terms as "knowledge", "perception", or "probability" are used, and formulate definitive rules for their use in order to avoid verbal confusion.

The fundamental concept underlying epistemology is "truth". In everyday life, and in early versions of epistemology, truth is understood as correspondence of a statement or concept with reality, *i.e.* the correspondence between the representation and what it represents. This common-sense conviction, called *the correspondence theory of truth*, was often questioned in the XX-century epistemology; the main objection was related to the understanding of the correspondence between the statement and the topic. Consequently, new criteria of truth appeared, *e.g.*: the agreement (consent) of a community (of experts and also of laypeople) that decides at any time what is true or false within the community; the practical usefulness of an opinion that claims to be true; the intuitive evidence of a statement, with the truth of a statement justified if it is directly clear and plausible. The pragmatic theory of truth defined it by the statement: "An idea is *true* so long as to believe it is profitable to our lives". The coherence theory of truth stated that a proposition's truth consists in its fitting into a coherent system of propositions.

The understanding of truth is of critical importance for philosophy (or methodology) of science being a chapter of philosophy that is involved in investigation on how scientific theories are developed, assessed, and changed; and whether science is capable of revealing the truth about hidden entities and processes in nature. Much of the philosophy of science is indistinguishable from epistemology, a subject considered by almost every philosopher, while most scientists prefer to get on with *doing* science rather than considering how science *is done.* The same applies to engineers and other practitioners.

3. REALISM VS. INSTRUMENTALISM

Various definitions of truth imply various methodological orientations that, in turn, lead to various interpretations of the concept of "measurement", and different understanding of epistemological status of measurement. There are two basic options in this respect: realism and instrumentalism.

It is a widely-accepted conviction that one of the aims of science is to construct theories that provide a "correct" description of the observable aspects of the world, the theories that enable one to predict what is observable but not yet observed. There is no common agreement, however, whether science ought also to aspire to the truth about what is unobservable[1]. Those who claim that science should and does reveal the hidden structure of the world are called *realists*; for them, theories attempt to describe that structure. For realists, scientific progress mainly consists in generating increasingly precise descriptions of a largely invisible world. By contrast, those who insist that science has only to register the observable phenomena are known as *instrumentalists*, since for them theories are not descriptions of the invisible world but only instruments for predictions about the observable world. The radical instrumentalists deny that theories can describe unobservable aspects of the world. More moderate instrumentalists claim that theories are descriptions, but only of the observable world. The most influential contemporary version of instrumentalism, known as *constructive empiricism,* adopts a third approach:

– all that matters is that the theory yields only true predictions concerning what could in principle be observed;
– scientists, however, are never entitled or required to believe that the theory is true;
– the most that can or need be known is that observable consequences of a theory – past, present, and future – are true.

Realists argue for scientific realism by pointing to its ability to explain the predictive success of scientific theories: the success would, they claim, be miraculous were the theories not at least approximately true. On the other hand, one of the most popular of recent arguments for instrumentalism is "pessimistic induction": from the point of view of present science, almost all sophisticated theories established more than, for example, 50 years ago, can be seen to be false; but if all past theories are found incorrect, one may reasonably infer that all or virtually all present theories will be found wrong 50 years hence. According to the instrumentalists, despite of this discontinuity in the history of theories, there has been a steady and cumulative growth in the scope and accuracy of their observable predictions; they have become increasingly better at saving the phenomena, their only proper task.

The century-long debate between realists and instrumentalists has generated arguments on each side. They are summarized in numerous books on philosophy of science, such as [3] or [4]. But the question: *are realism and instrumentalism methodologically indifferent?,* remains open. A. Kukla has recently argued that no scientific practices have yet been established to be incompatible with either realism or instrumentalism [5]. At the same time, R. F. Hendry has raised serious doubts about whether realism and instrumentalism are indifferent with respect to the practice of science, [6]. On the other hand, T. A. F. Kuipers has undertaken an attempt to synthesize both approaches to the philosophy of science [7].

4. TWO STANCES – TWO LANGUAGES

Measurement is a principal tool of empirical domains of science. That's why the methodological stance of researchers in those domains directly reflects on their understanding of measurement, and – consequently – on the conceptual basis and language they talk measurement science. This observation will be illustrated with an example of particular importance, *viz.* mathematical modelling of physical objects. The importance of this example is due to the fact that meas-

[1] It should be noted that there is no general agreement in the philosophy of science on what should be understood by "observable" and "unobservable" phenomena.

urement may be always interpreted as a particular case of such modelling.

The general organization of elementary operations any procedure of mathematical modelling consists of is shown in Fig. 1 [1]. Let's now briefly compare the descriptions of this procedure in the language of extreme realists and in the language of extreme instrumentalists.

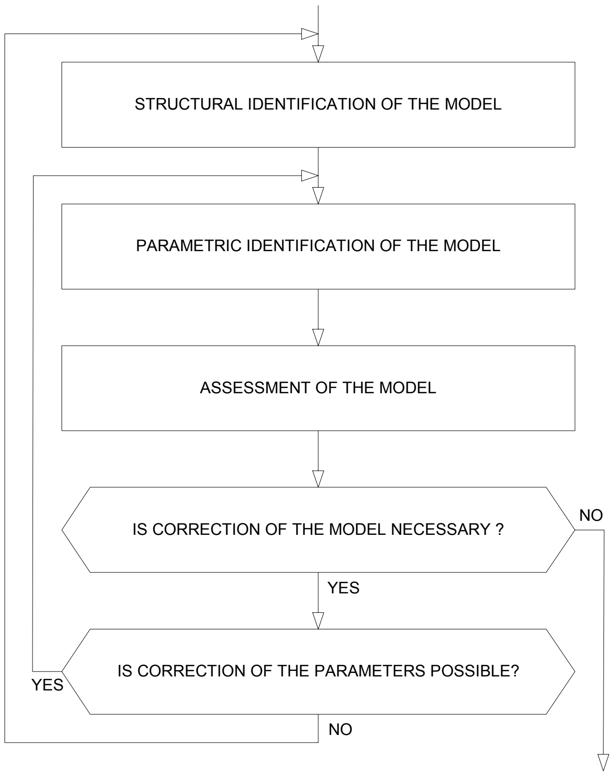

Fig. 1.

4.1. Physical object

Let's assume[2] that realists and instrumentalists have agreed that a physical object to be modelled is a fragment of reality separated from its surrounding by clear boundaries – most frequently discontinuities of mass density. They agreed as well that the existence of those boundaries does not mean that there is no interaction between the object and its surrounding: an exchange of energy or mass is going on, and it is characterized by means of quantities, such as flux of energy, flux of mass, flux of volume or density of energy, field of flow velocity, electric field strength. They have found acceptable a classification of those quantities into four groups:

- input quantities, identified with the causes of physical phenomena in the object, called also stimuli;
- output quantities, identified with the effects of physical phenomena in the object, called also responses;
- influence quantities whose values are stabilised during the operations related to the creation or use of the model;
- disturbances which imply the discrepancy between the responses of the model and of the object to the same stimulus.

[2] This is not an evident assumption: the differences in understanding of fundamental concepts could make such agreement impossible.

4.2. Mathematical model

For realists, the mathematical model of a physical object is its description (using numbers, variables, sets, equations, functions, relations, images, *etc.*) which provides true knowledge about this object. Since it contains truth, it may be used as a valid basis for justified statements about reality. Therefore, realists are inclined to speak about identification of the object rather than about identification of its model. Consequently, mathematical modelling is for realists a sequence of operations aimed at determination of the structure of the object and measurement of its parameters. Realists acknowledge that any model reflects only some phenomena in the object or some its properties, but stress that this is due to the limitation of the cognitive means rather that to an arbitrary decision of the model designer. Realists acknowledge that the knowledge of the phenomena in the object is always limited and uncertain, but they point out that by being constantly improved – it may asymptotically approach truth.

For instrumentalists, the mathematical model of a physical object is a mathematical formalism (including numbers, variables, sets, equations, functions, relations, images, *etc.*) which enables one to approximately predict the behaviour of the object under various conditions – in order to use it for various practical purposes. The procedure for identification of the mathematical model of a physical object is a sequence of operations aimed at selection of an adequate structure of the model (structural identification of the model), and estimation of its parameters (parameter identification of the model). Instrumentalists clearly state that the model reflects only some phenomena in the object or some its properties, namely those which are important for potential (intended) applications of the model. They avoid any statements on the relationship between the model and reality.

4.3. Structural identification

There are two basic approaches to structural identification: the black-box approach and the structural (or white-box) approach. The first one consists in identification of the input-output relationship exclusively on the basis of input-output data. The second one assumes some *a priori* knowledge of the internal structure of the modelled object, *viz.*: the list of elements the modelled object is composed of or may be decomposed into; the mathematical models of all those elements, assumed to be verified or validated; the list of links among the elements; the mathematical models of those links, assumed to be verified or validated.

Realists and instrumentalists agree that structural identification hardly can be organized as an algorithmic procedure, but they draw different conclusions from this observation. Realists say that it should be based on the knowledge of the modelled object, of its structure and other features, while instrumentalists claim that, as a rule, the choice of the structure of the model is based rather on some intuitive premises, on anterior experience or trial-and-error methodology. Consequently, realists prefer white-box models or even dismiss black-box models as non-scientific, while instrumentalists do not discriminate any type of models and evaluate them on the basis of the result of their application in practice.

4.4. Parameter identification

Regardless of whether the black-box approach or white-box approach is used for structural identification, parameter identification must be based on the result of measurements carried out on the modelled object. Nevertheless, the understanding of this operation by realists and instrumentalists is different. Realists claim that the parameters of the model – if it is properly designed during structural identification – are preferably physical quantities that should be directly measured rather than computed on the basis measurement results. Instrumentalists are not interested in the nature of the parameters but rather in their numerical influence on the model behaviour, characterized – for example – by the sensitivity of the criteria, used for model validation, to their variations. This difference is consistent with realists' preference for white-box models and instrumentalists' preference for black-box models.

4.5. Truth vs. inadequacy and inaccuracy of the model

For realists, the mathematical model of a physical object is a form of knowledge about this object containing the elements of objective truth. Realists believe that by consecutive improvements the model may unlimitedly approach reality. Thus, they implicitly assume the existence or possibility of an ideal model. They accept, of course, the fact that the model of a physical object yields only an approximate prediction of its behaviour and properties, but are inclined to explain this fact by the imperfection of our cognitive capabilities. Instrumentalists avoid any statements on the relationship of the model to reality, and put emphasis on its ability to meet requirements concerning its applicability for a pre-defined purpose.

Both realists and instrumentalists accept the fact that the model structure is always up to certain degree not adequate, and that the model parameters are always determined inaccurately. Realists are inclined, however, to attribute the non-adequacy of the structure of the model to the limited cognition of the modelled object, in particular – to neglecting some factors, important for the phenomena in the object or for its properties, during the choice of the quantities modelling the object (input, output and influence quantities) or inappropriate specification of the those quantities. Instrumentalists focus their explanation on the choice of the structure of the model, inappropriate from mathematical point of view.

Realists and instrumentalists agree that the estimates of the parameters of the model are uncertain due to the errors of the method of parameter identification, the errors of technical implementation of this method, and the errors in the data used for identification. Instrumentalists easily accept the fact that – in practice – the assessment of that uncertainty may be done only by comparison of the model under consideration with an extended model, not with reality. Consequently, they avoid the term *model verification* (derived from Latin *verus* = true). Realists always look for an absolute reference...

5. INSTEAD OF CONCLUSION

Depending on the educational background (science, engineering, ...) and on the kind of professional experience (theory, software, hardware, ...), the experts in the field of measurement science are inclined to use rather realists' or rather instrumentalists' conceptual basis and language. As a consequence, many professional discussions – carried out at learned institutions, during meetings, seminars and conferences – deflect from the principal issue, concentrate on imponderables, and end in nothing because of the impossibility to properly identify the essence of the opinion divergence. This observation, derived from 30-year experience of participation in such discussions – the observation referring, in fact, to the tradition of logical empiricism – has inspired the author to write this paper with the aim to suggest methodological reflection on scientific realism and instrumentalism as the catalytic means for moderating learned discussions on hot topics of measurement science ...

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