Information Content of the Model for Calculating the Finite Precision of Measurements

Boris Menin[1]

Mechanical & Refrigeration Consultation Expert, 9 Yakov Efrat St., Beer-Sheba 8464209

Research Article

.

ABSTRACT

Aims: We argue that the choice of a specific qualitative–quantitative set of variables in a model by a conscious observer fundamentally limits the achievable accuracy of the measurement process.

Place and Duration of Study: Mechanical & Refrigeration Consultation Expert, between January 2020 and July 2020.

Methodology: Using the concept of “finite information quantities” introduced by Gisin, we try to present it as a practical tool in science and engineering in calculating the proximity indicator of a model to the phenomenon being studied.

Results: The formulated metric (comparative uncertainty) allows us to set the optimal achievable uncertainty of the model and to confirm the impossibility of implementing the principle of infinite precision.

Conclusion: Any attempt to search for a universal physical theory must consider the uncertainty caused by the observer’s vision and the working of the human brain.

Keywords: Information entropy, measurement uncertainty, measurement units, mathematical model, observability, precision engineering, modeling, random variables.

1. INTRODUCTION

What can people model in their heads? Can a person calculate the value of the Planck constant in his head to draw a line between the macrocosm, where the laws of Newtonian mechanics operate, and the microworld, where the laws of quantum mechanics come into force? Where is the granularity of the reproduced observable picture of the world? All of the above fit into the Popper triad [1] of interaction “Physical world—Information and knowledge—Mental world (a conscious observer).”

Considering the results presented in [2,3], the writer offers a model of reflection (modeling a physical phenomenon) of the researcher/observer and a measure of complexity associated with this. We apply the model and the calculated metric to the problem of ultimate achievable precision when measuring the studied variable. One of the most original reviews of the advantages and disadvantages of statistical methods used to analyze experimental results is presented in [4], in which the extended uncertainty is used to analyze data on the uncertainties inherent in model variables and the uncertainties of experimental results conducted by various laboratories with different measurement methods. However, the presented approach plays by different rules than the standard statistical analysis of theoretical and experimental data with expert evaluation and measurement theory, the principles of which will be true forever and ever. It is explained by the fact that special attention is paid to systematic uncertainty due to the researcher's choice of a qualitatively-quantitative set of variables in the measurement model. This uncertainty is inherent in any models in physics and engineering and, in fact, is the initial one, after which the observer/research team carefully calculates the possible uncertainties of all chosen variables before and after the experiment, using modern mathematical methods of data processing [5]. It is considered a "subjective reality," which exists depending on the mind or knowledge of the observer.

The methods of modern science emphasize the importance of information for measurement and evaluation, which, in turn, are technical tools for observation and experiment in science, as well as for engineering. For several decades, publications on the theory of information and its application in physics indicate two mutually exclusive approaches to assessing the nature of information entropy. According to the first, information entropy is only an abstract, mathematically well-formalized concept and a subjective, measurement-system-dependent feature [6– 8]. As is usually the case in science, the opposite opinion exists. In most of the literature, researchers (see, for example, [9–17]) consider information as a kind of specific substance, as well as a natural, technological and social phenomenon [18]. That is why it is so important to explain and understand the features of modeling a physical phenomenon or process. This fully applies to information entropy.

Recently published articles claim that the properties of the physical world are independent of our observations of them [19]. At the same time, it is obvious that any physical systems are described in terms (dimensional and dimensionless variables), depending on the observer and thanks to his knowledge, experience and intuition. In other words, the details of observation depend on the frame of reference of the observer or the "free will" of a person. Thus, from the standpoint of the statistical theory of information, the information content embedded in the measurement process model (MPM) takes on a special meaning: it is due to the freedom of the observer's thought to choose one or another variable from the set of all possible variables. In this context, according to the suggested approach, the human evaluation of information is completely ignored. In other words, the set of 100 musical notes played by chimpanzees will have exactly the same amount of information as that of the 100 notes played by Mozart in his Piano Concerto No. 21 (Andante movement).

In turn, information entropy is manifested through the interaction of the measured physical system (PS) and the MPM. MPM can be defined as a physical, conceptual description of a real phenomenon using mathematical concepts and language to facilitate a correct explanation of the system or to study the influence of various variables and to predict patterns of behavior [20]. Moreover, the model is a kind of communication channel [21] between the observer and the phenomenon under study. However, this definition is not accurate, since the MPM is not a material medium and does not transmit information, but only presents it in the mind of the observer.

The method of reasoning, in which PS (the object of study) is reflected in the MPM used by the experimenter, is very common in the natural sciences, where observers use the MPM to describe the object of their research, and the structure of the MPM affects the results of observations and determines their accuracy. For example, when a physicist uses an MPM with a small number of variables and an MPM with a large number of variables, she or he gets two different answers. Obviously, although the compared models describe the same PS, qualitative and quantitative differences in the use of variables lead to differences in the results, magnitudes of the uncertainties of the MPM and to differences in the requirements for checking the accuracy of experiments.

The uniqueness of the situation lies in the fact that the information content embedded in MPM is determined by measurable physical variables (hereinafter we will use the term “finite information quantity” (FIQ) [22]), chosen by the observer in accordance with his vision from a particular system of units, for example, SI (International System of Units) or CGS (centimeter-gram-second). Therefore, in this case, changes in information entropy of MPM are subjective. Please note that in practical situations of the MPM formulation, perturbation is not introduced into the PS (in fact, there is an idealistic situation in the modeling process without energy losses), that is, the observer only imagines the picture of the observed PS and conducts a thought experiment. When an MPM is built, it consists of various FIQs, which can contain a deterministic data set or a discrete one, or both. Therefore, the assertion [23] that informational entropy is zero for any deterministic data set does not apply to MPM.

In this article, we want to demonstrate that a model of a phenomenon can be assimilated with a thermodynamic system and information entropy so that we can estimate the model uncertainty associated with a quantitative and qualitative set of FIQs. Innovation is associated with the rethinking of the physical nature of the model that describes a phenomenon or process. Our goal is to verify how, in the formation of the model, its information entropy is related to the accuracy of the reproduction of the observed object, and how the calculated uncertainty allows us to make assumptions about the preference of a particular measurement method in a particular measuring process. All subsequent considerations relate to the moment of completion of the MPM construction (a qualitative and quantitative set of FIQs is determined) before the researcher/scientific team conducts any calculations to identify the magnitude of various uncertainties inherent in one or another selected FIQ in the MPM.

In addition, we strive to present the process of observing a physical phenomenon (measuring a variable) in terms of dependence on the observer. Our goal is to show that the use of the concept of “amount of information contained in the model” allows us to estimate the magnitude of its uncertainty in the context of the implementation of subsequent measurements made by the observer. Next, we show how, using the concepts and mathematical apparatus of information theory, it is possible to establish the limit of precision of any measurement process (the “blurriness” of the observed phenomenon) and even a physical law.

2. MODELING THROUGH OBSERVER VISION

One possible problem in modeling PS, isolated from the environment, is how the observer evaluates experiential information [18] about PS. The observed PS is linked to the environment by a huge number of connections. However, the observer, at his discretion, isolates from this environment only important, from his point of view, interactions and FIQs (“the disorder is in our heads, in our knowledge of a system” [24]). Thus, he destroys those ties that seem insignificant to him. Factually and importantly, information about PS is not transmitted to MPM by material components. It is created by the modeler’s will without any energy dissipation. In addition, by itself, there is no need to discuss any boundary conditions and ambient temperature for the MPM itself because MPM is not the medium. On the other hand, MPM is a unique lens by which the observer perceives the PS, distinguishing it from the environment. This process is called selective perception. We see what we wish to see, and we twist messages around to suit ourselves [18].

It must be emphasized that the behavior of the observer when constructing finite structural objects [18] (in our case, this is MPM) obeys some algorithm that determines the complexity of the formulated MPM. Such algorithmic complexity is determined by a qualitative–quantitative set of FIQs necessary for an accurate description of the object in question.

For our research, and with some practical intuition thrown in, assume that the PS has a specific number of properties (criteria, FIQs) that characterize its content. Then, we assume that each FIQ represents the original readout (reading [9], [25], [26]), through which some information on the researched field ***U*** (observed object, PS) can be obtained by the observer. In other words, the researcher observing a physical phenomenon, analyzing the process or designing the device, selects—according to his experience, knowledge and intuition—certain characteristics of the object. With this selecting of the object, connections of the actual object with the environment enveloping it are destroyed. In addition, the modeler considers the relatively smaller number of quantities than the current reality due to constraints of time, and technical and financial resources, for example, 10, 20, 50 or even 130 variables [27]. Therefore, the "image" of the object being studied is shown in the model with a certain uncertainty, which depends primarily on the number of FIQs considered. In addition, the object can be addressed by different groups of researchers, who use different approaches for solving specific problems and, accordingly, different groups of FIQs, which differ from each other in quality and quantity. Thus, for any physical or technical problem, the occurrence of a particular FIQ in the model can be considered as a random process.

Without loss of generality, but for simplicity, one may take a pragmatic view and consider a situation of objective reality when modeling a phenomenon in which the observer selects any FIQ in the model in a binary base [28]: 1 corresponds to the inclusion of the FIQ in the model, and 0 means the FIQ is ignored. The adoption of a value of 0 or 1 is carried out with equal "probability." If we get unreasonable results, this may be a sign that we are using information entropy incorrectly. However, if a specific proposal for a probabilistic measure allows us to solve some problems that cannot be solved in any other way, we will have reason to believe that we are moving in the right direction.

Thus, we can introduce the postulate of a priori equiprobability (maximum low predictability) of the appearance of any FIQ in the model. In confirmation of this, we would like to recall that the most famous example of such a situation is the fact of studying an electron as both a particle and a wave. We have no way to decide which interpretation is correct (unless the situation when someone intends to knock out an electron from the lattice using only two tools: a hammer and a chisel, to find out its size and shape. This will be recognized, at least, as the nonscientific method [29]). Although two qualitatively different sets of variables are used to describe the motion of an electron, as it turned out, both have the right to life, which led to the concept of electron dualism.

3. RESULTS NUMBERS OF FIQs IN SI

Various systems of units are used in science and engineering, for example, the Planck system of units [30], British–American System of Units [31] or the centimeter-gram-second (CGS) system of units [32]. However, the International System of Units (SI) is currently the most widely used system. For the convenience of further discussion, but without loss of generality, we choose SI. An additional reason is that SI units are also used by the CODATA (Committee on Data for Science and Technology) methodology [33]. In the future, we will show that the conclusions do not depend on the choice of a specific system of units.

The SI is a product of human ingenuity, not nature. Is there a special reason why SI should continue to be respected? Maybe, at some point, the SI will break. The question is when? Not responding immediately to the questions asked, we note the important features of this system.

FIQ ***q*** (which may be the scalar parameter time, a universal constant, as well as a one-dimensional component of the position or the momentum, etc. [22]) is assumed to take values in the domain of real numbers R, i.e., ***q*** ∊ R. Moreover, the dimension of any ***q*** of SI can be expressed as a unique combination of dimensions of the main base quantities (***L***–length, ***M***–mass, ***T***–time, ***Θ***–thermodynamic temperature, ***I***–electric current, ***J***–light intensity and ***F***–amount of substance) to different powers [34]:

$$\boldsymbol{q} \text{ å } \boldsymbol{L}^{l} \cdot \boldsymbol{M}^{m} \cdot \boldsymbol{T}^{t} \cdot \boldsymbol{I}^{i} \cdot \boldsymbol{\Theta}^{\Theta} \cdot \boldsymbol{J}^{j} \cdot \boldsymbol{F}^{f}\ , \qquad (1)$$

where *l*, *m*, …, *f* are the exponents of the base quantities and take only integer values: {*l*, *m*, …, *f*}∊ Z ∊ R, Z denotes the set of integers that vary in certain intervals [35], [36]

$$-3 \le l \le +3, -1 \le m \le +1, -4 \le t \le +4, -2 \le i \le +2,$$

$$-4 \le \theta \le +4, \quad -1 \le j \le +1, \quad -1 \le f \le +1. \qquad (2)$$

$$\mathrm{e}_{l} = 7,\ \mathrm{e}_{m} = 3,\ \mathrm{e}_{t} = 9,\ \mathrm{e}_{\theta} = 5,\ \mathrm{e}_{j} = 3,\ \mathrm{e}_{f} = 3,\ \mathrm{e}_{l} = 7,$$

where e_l, e_m, …, e_f are numbers of options of changes for the exponents of the base quantities.

Each ***q*** defined by (1) contains a “portion of information” [18] or a “finite amount of information” (the information content of each FIQ is bounded above [22]) about PS.
Let us calculate the number of FIQs contained in SI (a similar operation can be carried out for other systems of units):

$$\psi^{\mathrm{o}} = \mathrm{e}_{l} \cdot \mathrm{e}_{m} \cdot \mathrm{e}_{t} \cdot \mathrm{e}_{\theta} \cdot \mathrm{e}_{j} \cdot \mathrm{e}_{f} \cdot \mathrm{e}_{l} - 1 = 76{,}544, \qquad (3)$$

where “–1” corresponds to the case where all exponents of the base quantities in formula (1) are treated to zero dimension.

The value Ψ° includes both required and inverse FIQs (for example, L^1 is the length, L^{-1} is the running length). The object can be judged knowing only one of its symmetrical parts, while others structurally duplicating this part may be regarded as information empty [37]. Therefore, the number of options of dimensions may be halved. This means that the total number of dimension options of FIQs without inverse FIQs equals Ψ = Ψ°/2 = 38,272.
For further discussion, we use the methods of the theory of similarity. It is motivated by the desire to generalize obtained results in the future for different areas of physical applications. Moreover, the universality of similarity transformations is defined by the invariant relationships that characterize the structure of all the laws of nature. According to the π-theorem [38], the number μ_{SI} of possible dimensionless criteria with **ξ** = 7 base quantities for SI will be:

$$\mu_{\mathrm{SI}} = \Psi - \xi = 38{,}265. \qquad (4)$$

It should be noted that the set of dimensionless criteria, μ_{SI}, does not exist in physical reality. This is a constant and cannot be optimized. However, the observed PS, which actually exists, can be represented by elements of this set. In addition, μ_{SI} is an important characteristic of the algorithmic complexity [39] of SI. Moreover, μ_{SI} may be considered as a subgroup of the infinite Abelian group representing all dimensionless variables [40].
It should be emphasized that μ_{SI} reflects the fundamental abolition of the principle of infinite precision. Because the information content of FIQ is always limited [22], and the μ_{SI} contains

a finite number of FIQs, the maximum amount of information contained in the MPM about PS is also finite. Thus, it can be argued that, in principle, there is a limit to the possibility of knowing (or measuring) the researched FIQ. Moreover, this limit is much stricter (stronger) than the Heisenberg uncertainty principle and can be introduced both in quantum physics and in classical physics. Further, we will propose a calculation of the magnitude of the initial and unrecoverable PS uncertainty caused by this precision limit with which the FIQ can be determined (measured).

In the conclusion of this chapter, it should be noted that SI includes the base and derived FIQs used to describe various classes of phenomena (CoP). In other words, the additional limits of PS description are determined by the choice of CoP and the number of the derived FIQs considered in the MPM [41]. For example, usually, when simulating heat transfer processes, ***L***–length, ***M***–mass, ***T***–time and ***Θ***–thermodynamic temperature, i.e., $\mathrm{CoP}_{\mathrm{SI}} \equiv$ ***LMTΘ***, are used. From the point of view of the proposed approach, SI contains the maximum amount of information about the world in comparison with any MPM relating to any PS.

4. AMOUNT OF INFORMATION EMBEDDED IN MPM

When considering μ_{SI} criteria, which have equal probabilities of observer accounting when constructing MPM, and following the formalism of Landsberg [42] and Lloyd [2], it is possible to obtain the SI information entropy

$$H = k_{\mathrm{b}} \cdot \ln \mu_{\mathrm{SI}}\,, \qquad (5)$$

where k_{b} is the Boltzmann constant.

The traditional way of thinking suggests that if we leave the system alone, it will be in balance; we need to exert force to divert it from balance. At the same time, the informational interpretation allows us to see the MPM in a new light: when a researcher chooses the influencing criteria (the conscious limitation of the number of FIQs that describe an object, in comparison with the total number μ_{SI}), the entropy of the mathematical model changes *a priori*. The MPM entropy change ΔH is generally measured as follows [9]:

$$\Delta H = H_{\mathrm{pr}} - H_{\mathrm{ps}}\,, \qquad (6)$$

where ΔH is the entropy difference between the two cases, pr is “*a priori*” and ps is “*a posteriori*.”

“The efficiency Q of the experimental observation method can be defined as the ratio of the information obtained to the entropy change accompanying the observation” [9]. During a thought experiment, no distortion is brought into the MPM, that is why $Q = 1$. Then, one can write according to (6):

$$\Delta A = Q \cdot \Delta H = H_{\mathrm{pr}} - H_{\mathrm{ps}}\,, \qquad (7)$$

where ΔA is the *a priori* amount of information embedded in the MPM.

Using equations (6) and (7) and introducing symbols where z' is the number of FIQs in the selected CoP and β' is the number of base quantities in the selected CoP leads to the following equation:

$$\Delta A' = Q\cdot(H_{\mathrm{pr}} - H_{\mathrm{ps}}) = 1\cdot[k_{\mathrm{b}}\cdot\ln\mu_{\mathrm{SI}} - k_{\mathrm{b}}\cdot\ln(\mathrm{z}'-\beta')] = k_{\mathrm{b}}\cdot\ln[\mu_{\mathrm{SI}}/\ln(\mathrm{z}'-\beta')], \quad (8)$$

where Δ*A*' is the *a priori* amount of information embedded in the MPM due to the choice of the CoP.

The value Δ*A*' is linked to the *a priori* absolute uncertainty of the MPM, caused only by the choice of the CoP, Δ'_{mpm} and *S*, the interval of observation of the main researched FIQ, through the following dependence [9]:

$$\Delta'_{\mathrm{mpm}} = S\cdot\exp(-\Delta A'/k_{\mathrm{b}}). \quad (9)$$

Substitution of (8) into (9) gives the following dependence:

$$\Delta'_{\mathrm{mpm}} = S\cdot(\mathrm{z}'-\beta')/\mu_{\mathrm{SI}}. \quad (10)$$

Following the same reasoning, it can be shown that the *a priori* absolute uncertainty of the MPM, caused by the number of recorded dimensionless criteria chosen in the MPM, Δ''_{mpm}, takes the following form:

$$\Delta''_{\mathrm{mpm}} = S\cdot(\mathrm{z}''-\beta'')/(\mathrm{z}'-\beta'), \quad (11)$$

where z'' is the number of FIQs recorded in MPM, β'' is the number of base quantities recorded in MPM and Δ''_{mpm} cannot be defined without declaring the chosen CoP (Δ'_{mpm}).

What is the possible structure of the total MPM uncertainty Δ_{mpm}? To answer this question, we turn to [43]. The author has proven a theorem which is interpreted as an assertion that the total information amount can be separated into information identifying the element of the partition, plus the average information identifying an element within subsets of the partition. Considering this conclusion, we can represent the total *a priori* absolute uncertainty of the MPM, Δ_{mpm}, as the sum of two terms, in which the first term defines Δ'_{mpm} and the second term dictates the choice of Δ''_{mpm}:

$$\Delta_{\mathrm{mpm}} = S\cdot[(\mathrm{z}'-\beta')/\mu_{\mathrm{SI}} + (\mathrm{z}''-\beta'')/(\mathrm{z}'-\beta')], \quad (12)$$

where $\varepsilon = \Delta_{\mathrm{mpm}}/S$ is the comparative uncertainty [9].

There are several interesting features inherent in Equation (12). First, this equation applies to the MPM, in which any FIQs, both dimensional and dimensionless, are used [44]. Equally important, it declares that the precision limit for measuring the researched main FIQ for a given class of phenomena (z' – β') and the selected number of considered FIQs in the model (z'' – β''), clearly defines the smallest value of the comparative uncertainty Δ_{mpm}/S of the main function under study. In addition, the equivalence property is inherent in Equation (12). Equivalence ensures that the structure of the model remains unchanged, regardless of which unit systems are used. It is noteworthy that Equation (12) refutes the principle of infinite precision: no unique measuring equipment, improvement of existing and creation of new measurement methods, the use of powerful computers together cannot overcome the barrier imposed by Equation (12). The point is not in their possible imperfection, but in how the human brain works. According to Equation (12), observation is not a measurement, but a process that creates a unique physical world in relation to each specific observer.

Not unimportant is the fact that the choice of any of the various existing systems of units, in principle, does not affect the stated features of Equation (12). This can be shown using Equation (8). Imagine that the number of dimensionless criteria and numbers in the extended system of units (numbered “2”) is equal to μ_2 and $2\cdot\mu_{SI} = \mu_2$. Given that $\ln\mu_{SI} >> \ln(z''–\beta'')_{SI}$, $\ln\mu_2 >> \ln(z''–\beta'')_2$, and $\ln\mu_{SI} >> \ln 2$, we can obtain the following relations

$$\Delta A_e = \Delta A' + \Delta A'' = k_b \cdot \ln[\mu_{SI} / (z' - \beta')] + k_b \cdot \ln[(z' - \beta') / (z'' - \beta'')] = k_b \cdot \ln[\mu_{SI} / (z'' - \beta'')], \tag{13}$$

$$\Delta A_{eSI} / \Delta A_{e2} = [\ln \mu_{SI} - \ln(z' - \beta')_{SI}] / [\ln \mu_2 - \ln(z'' - \beta'')_2] = \ln \mu_{SI} / [\ln 2 + \ln \mu_{SI}] \approx 1, \tag{14}$$

where Δ*A*'' is the *a priori* amount of information due to the choice of the number of all FIQs registered in the chosen MPM, ΔA_e is the total amount of information contained in the MPM, ΔA_{eSI} is the total amount of information contained in the MPM, in which the used FIQs are from SI, ΔA_{e2} is the total amount of information contained in the MPM, in which the used FIQs are from the extended system of units.

To check the optimal number of criteria corresponding to a specific CoP, one needs to take the derivative of Δ_{mpm}/S (12) with respect to z' – β' and equate it to zero:

$$(z'' - \beta'') = (z' - \beta')^2 / \mu_{SI}. \tag{15}$$

Let us apply (2), (4) and (15) for the thermal–mechanical process ($CoP_{SI} \equiv \boldsymbol{LMT\theta}$).

$$(z' - \beta')_{LMT\theta} = (e_l \cdot e_m \cdot e_t \cdot e_\theta - 1) / 2 - 4 = 846, \tag{16}$$

$$\gamma_{LMT\theta} = (z'' - \beta'')_{LMT\theta} = (z' - \beta')^2_{LMT\theta} / \mu_{SI} \approx 19, \tag{17}$$

where $\gamma_{\boldsymbol{LMT\Theta}}$ is an optimal number of criteria in a model inherent in $CoP_{SI} \equiv \boldsymbol{LMT\Theta}$; “–1” corresponds to the case where the exponents of all the base quantities are zero in Equation (1); 4 corresponds to the four base quantities ***L***, ***M***, ***T*** and ***Θ***; and division by 2 indicates that there are direct and inverse FIQs, e.g., $\boldsymbol{L}^1$ is the length and $\boldsymbol{L}^{-1}$ is the run length. The object can be judged based on the knowledge of only one of its symmetrical parts, while the other parts that structurally duplicate this one may be regarded as information empty [37]. Therefore, the number of options for dimensions is reduced by a factor of two.

Then, one can calculate the optimal achievable comparative uncertainty $\varepsilon_{\boldsymbol{LMT\Theta}}$:

$$\varepsilon_{LMT\theta} = 846 / 38{,}265 + 19 / 846 = 0.0442 \tag{18}$$

We will apply the considered concept to several examples.

5. LIMIT OF PRECISION IN CALCULATING DIGITAL INFORMATION CHARACTERISTICS OF A COMPUTER

In [2], Lloyd calculated the number of operations per second, *R* that could be performed by the ultimate laptop. He showed

$$R = k_{\mathrm{b}} \cdot \mathrm{T} / \hbar, \text{ bits/s,} \qquad (19)$$

where T is the temperature of 1 kg of matter in a maximum entropy in a volume of 1 liter, $\hbar$ is Planck's reduced constant.

Given the dimensions of the FIQs in (19), the problem belongs to the CoP$_{\mathrm{SI}}$ ≡ ***LMTΘ***, and we can assume that z'' – β'' = 1 (according to the π-theorem [38]).

To find the value of an absolute uncertainty (Δ*R*), the mathematical apparatus of differential calculus may be applied [45]:

$$\Delta R = \sum_{i=3}^{1} \left| (\partial R / \partial \xi_i) \cdot \Delta \xi_i \right|, \text{ bits/s,} \qquad (20)$$

where $\partial R / \partial \xi_i$ are partial derivatives of the function *R* with respect to three FIQs, $\Delta \xi_i$ is the absolute uncertainty of each FIQ measurement.

What magnitudes of FIQs used in (20) would be applicable? Unfortunately, at the moment, in most scientific and technical publications, there is no detailed information, *including both absolute and relative uncertainties of the measured FIQ, as well as a comparison of the difference between experimental and theoretical data and the achieved overall uncertainty of the studied FIQ*. These data are required for confirmation of testability, veracity, validity and ability to reproduce the declared results. Therefore, it is difficult for the reader to push or reject the formulated models and ideas, and such a situation has developed in the most diverse fields of science and engineering, for example, in psychological science, metallography, physics, life sciences, economics and refrigeration [46] – [52]. Therefore, the writer, with great care, chose the data, realizing that readers may have a different opinion. So, Boltzmann's constant, $k_{\mathrm{b}} = 1.3805 \cdot 10^{-23}$ m²·kg/(s²·K) [2], its relative r_{kb} and absolute Δk_{b} uncertainties, respectively, equal $1.1 \cdot 10^{-6}$ and $1.5 \cdot 10^{-29}$ m²·kg/(s²·K) [53]; Planck's reduced constant, $\hbar = h/(2\pi) = 1.054571817 \cdot 10^{-34}$ m²·kg/s [2], its relative r_h and absolute Δh uncertainties, respectively, equal $1.3 \cdot 10^{-8}$ and $8.6 \cdot 10^{-42}$ m²·kg/s [54]; the temperature of the computer T = 300 K [2], its measurement uncertainty $\Delta \mathrm{T} = 1.0 \cdot 10^{-3}$ K (to achieve an uncertainty of $3 \cdot 10^{-3}$ K at 300 K requires a measurement time of at least 27 h [55]). So, we can calculate Δ*R*:

$$\Delta R = \left| (\partial R / \partial k_{\mathrm{b}}) \cdot \Delta k_{\mathrm{b}} \right| + \left| (\partial R / \partial \mathrm{T}) \cdot \Delta \mathrm{T} \right| + \left| (\partial R / \partial \hbar) \cdot \Delta \hbar \right| = \left| (\mathrm{T} \cdot \Delta k_{\mathrm{b}} / \hbar \right| + \left| k_{\mathrm{b}} \cdot \Delta \mathrm{T} / \hbar \right| + \left| k_{\mathrm{b}} \cdot \mathrm{T} \cdot \Delta \hbar / \hbar^2 \right| = 1.3 \cdot 10^8 \text{ (bits/s)} \qquad (21)$$

Having calculated from the data already given, the value of *R*, one can also calculate the possible relative uncertainty of its determination r_R

$$R = 3.9 \cdot 10^{13}, \text{ bits/s,} \qquad (22)$$

$$r_R = \Delta \mathrm{R} / \mathrm{R} = 1.3 \cdot 10^8 / 3.9 \cdot 10^{13} \approx 3 \cdot 10^{-6} \qquad (23)$$

It would seem that the value of r_R is small enough to admit the validity of the proposed formula for *R*. To be convinced of this, we will calculate the achieved comparative uncertainty

$$\varepsilon_R = [(z' - \beta')/\mu_{SI} + (z'' - \beta'')/(z' - \beta')] = (846/38,265 + 1/846) = 0.0233 \quad (24)$$

Obviously, comparing (18) with (24), it can be argued that ε_R is significantly different from $\varepsilon_{LMT\Theta}$: $\varepsilon_{LMT\Theta}/\varepsilon_R \approx 1.9$. This is because when calculating *R* (in the MPM), the number of dimensionless criteria, 1, is much less than the recommended one, $\gamma_{LMT\Theta} = 19$ (17), that is, a large number of possible influencing factors were ignored. It should be noted that the principles of measurement theory do not allow us to predict the necessary accuracy when conducting quantitative calculations carried out by Lloyd. However, using the FIQ-based method, it is possible to justify the precision limit of the presented formula (19). We only have to wait 250 years [2] to make sure of the validity of this statement.

However, the same considerations in the validity (admissibility) of the presented calculation (19) can be expressed with respect to another original idea about the new principle of mass–energy–information equivalence. In [17], it states that information is not just physical, but it has nonzero and quantitative mass m_{bit}, while it stores information:

$$m_{bit} = k_b \cdot T \cdot \ln 2 / c^2, \text{ (kg)} \quad (25)$$

where c is the speed of light, $c = 2.9979 \cdot 10^8$ m/s [34].

In this context, it is shown [17] that the mass of one bit of information at room temperature (300 K) is $3.19 \cdot 10^{-38}$ kg. In this case ($CoP_{SI} \equiv \boldsymbol{LMT\Theta}$), the theory of measurements is powerless to make a specific judgment in defense or against the proposed calculation. In contrast, having performed similar reasoning within the framework of the FIQ-based method and after making calculations similar to (21)–(24), we can find the ratio between the theoretical value of comparative uncertainty and that achieved in (25): ≈ 1.9. This significant difference also indicates the difficulty of confirming the mass–energy–information equivalence principle. However, we do not know how many years it will take to verify it.

These two examples are united by the fact that when discussing the relevance of the results, the analysis of the uncertainty of the model was completely absent, especially, the possible analysis of the measurement uncertainty. Thus, any prognostic calculations, even being interesting, elegant, and attractive and having a clear physical thought, must be accompanied by appropriate explanations of the possible limits of their applicability.

So, when clarifying the limit of precision of the presented formulas (19) and (25) [2], [17], the reader has a natural question about the possibility of reaching this limit in the physically correctly formulated MPM. Because the optimality of the MPM is determined by comparison with the achieved comparative uncertainty including the observation interval, it is clear that in the practical case the limit cannot be reached. This is explained by the existence of the inevitable uncertainty of the MPM caused by the initial preferences of the researcher in the process of formulating the MPM. The magnitude of this uncertainty is an indication of how likely it is that the observer’s philosophical inclinations will influence the outcome of this process. Thus, if the initial assumptions of the FIQ-based method are true, the problem of modeling PS in both classical and quantum physics (in addition to the Heisenberg inequality) is associated with the existence of an unavoidable initial vision erosion (“fuzziness”) of the studied PS, which dictates the value of the precision limit for its description.

6. DISCUSSION

The presented approach allows us to determine the new role of information entropy in modeling.

In practice, there is always a situation where one and the same FIQ is measured, for example, by two different accurate measuring instruments that implement fundamentally different methods. Of course, it is possible to measure FIQ by different laboratories, but using the same method. We expect that in these two situations the results will be close ("a certain number of digits will remain unchanged" [22]). Although the opposite is also possible. In any scenario, to analyze the data, to establish the credibility of the results obtained, statistical methods (like the Bayesian approach or biased estimators method, the boundaries of which are well known [56]) are used with the mandatory involvement of experts, for example, as in the case of a very complicated CODATA procedure. The result is consistent values of the measured FIQ and its relative uncertainty, but without specifying the size of the possible interval of FIQ changes, which leads to an infinitely large value of entropy [9]. *De facto*, the level of measurement accuracy is determined by the existing instrumental base and the confidence of researchers in identifying all possible sources of uncertainties. In such a situation, questions about where the limit of definition of "new digits" [22] in the value of the measured FIQ and which method is more preferable remain open.

In defense of the right to present the FIQ-based approach instead of traditional statistical methods in the study of physical phenomena, we recall Gödel's work [57]. Gödel discovered that every strictly formal mathematical system has a natural field of application—but when rules are applied to inputs that do not have the same structure that determined the development of the rules, we can expect strangeness. The predictive ability of statistical methods, exacerbated by the need to use subjective expert opinion, is fundamentally limited by the sensitivity of the measurement and the fatal flaws of any calculations [58].

Statistical physics, generally speaking, is about the lack of information [59]. On the other hand, one of the most fruitful ideas of the 20th century is the use of information theory in modeling physical phenomena in various fields of science and technology to identify their inherent features. We can do this by formalizing the models by identifying a qualitative–quantitative set of FIQs selected by the conscious observer in the models. Thanks to this, there is a sharp paradigm shift due to the normalization of models according to the classes of phenomena. Instead of being interested in one or another probability distribution when analyzing the results of experimental and theoretical calculations of the uncertainties of the constructed models, we are primarily interested in the selected base quantities. Entire families (classes of phenomena) describing different methods of measuring FIQ are characterized by various comparative uncertainties. Therefore, the significance of the indicated characteristics of the FIQ-based method especially increases when it is applied to the analysis of experimental data on measurements of physical constants, which have been implemented over the years by various laboratories using similar or different test benches [60].

Calculated in accordance with the FIQ-based approach, comparative uncertainty seems fundamental and determined by the class of the phenomenon and the number of FIQs considered. In the proposed interpretation of the FIQ-based modeling process, the choice of physical variables is based on, in fact, the observer's tendency to make a philosophically sound and physically supported decision. In interpreting the FIQ-based modeling process presented here, this leads to the understanding that the limitations of the precision of measuring FIQ are not due to the imperfection of the measuring instruments, computational methods and insufficient computer power. This is an indicator of how much the philosophical inclinations of the researcher influence the outcome of the measurement process. At each stage of the construction of the MPM by the observer, there is complete confidence (the probability is zero) that the MPM will not correspond to the PS with a high degree of precision.

Comparative uncertainty representing a “systematic effect” [61], [62] and arising from the formulation of the MPM is neither random nor observable. It causes the initial irreparable “fuzziness” of the observed FIQ under investigation, which can be calculated using the amount of information contained in the MPM. Thus, this uncertainty imposes limitations on the value of achievable measurement precision. At the same time, comparative uncertainty is an element for which the traditional statistical approach and “expert judgment” [63] do not work at all.

It is important to emphasize that, in the context of the modeling process, the FIQ-based approach gave us good reason to believe that the fundamental limit of precision in determining the FIQ, on the one hand, is objective, but on the other hand, subjective due to the will of the “participant” [64]. The physical existence of a tacitly assumed and finite number of selected FIQs leads to a real situation where any PS is “blurred” in the eyes of the observer. The mind of the researcher is deprived of the opportunity to know the exact reality hiding in the shadow of the FIQ-based approach.

Answering a question that has not yet been asked, what the wrong in this approach is or where are its (reasonable) limitations, the following should be noted. This approach does not give any recommendations on choosing a specific FIQ from SI or another system of units, but only limits their number; the FIQ-based method requires the equiprobable appearance of the FIQs selected by the model designer; it completely ignores the knowledge, intuition and experience of developers; and the approach requires knowledge or declaration of the magnitude of the range of variation of the FIQ being investigated.

An analysis of various formulas obtained using the same comparative uncertainty provides a reliability check to assess confidence in these results. Conversely, two conflicting results about the same studied FIQ (for example, two calculated values of the Hubble constant, giving rise to a situation called the Hubble tension), measured using various methods with different classes of phenomena, indicate that the reliability of these results may need to be reviewed [44]. Thus, observation (the process of formulating the model) is a scientific problem, the possible solutions of which are realized by identifying previously unknown systematic errors, revising the original models, or discovering new theoretical knowledge [65].

The act of constructing MPM can be considered as a direct action of the mental world (observer) without energy dissipation, leading to the structuring of information about the physical world. However, the freedom of observer choice cannot be free from external pressure; the choice concerns only the internal alternatives of the decisions he makes. Thus, the problem of formulating the model here may be solved. Nevertheless, the topic of constructing a measurement process model should take its place in scientific discussions.

7. CONCLUSIONS

Any decision-making mechanism is inherently limited by the behavior of collecting and processing information from the system of which it is a part [66]. The proposed approach provides a relatively simple representation of the decision-making process, with which you can study the effect of the amount of information on the measurement modeling process.

We discussed the application of the theory of information and the concept of information entropy to the problem of constructing a model of a physical phenomenon, and more precisely, to the process of measuring a finite information quantity. We formulated and calculated the value of the comparative uncertainty characteristic of the measurement model with a specific class of the phenomenon. Then, we applied the proposed metric to the analysis of the possible precision limit of two examples linked to computer characteristics. However, the results obtained, probably, do not fit into the consensus generally accepted in the scientific community. Obviously, any new physical approach with all the results of various experiments must pass the test of time.

The proposed unconventional FIQ-based approach brings with it a crucial complement to the Popper triad. The model of the measurement process and the system of units from which FIQs are selected, although they are a product of human ingenuity, are interdependent. Their structure and interaction impose a fundamental limitation on the achievement of unprecedented accuracy of observation, modeling and, moreover, FIQ measurement, which, in turn, is associated with the observer's consciousness. This is completely opposite to the idea of the principle of infinite precision. In addition, this leads to the idea of limiting the possibility of knowing (or measuring) FIQ, to a situation where the description of a physical phenomenon is fundamentally incomplete, and to a standard interpretation of the Heisenberg uncertainty principle, but in a more "rigid" form, which is realized in everyday life. Accordingly, the uncertainty of the model, due to the choice of the class of phenomena and the qualitatively-quantitative set of FIQs, can be considered as the principle of finiteness [67]), with which scientists can analyze the accuracy of measuring physical constants and the limits of application of different formulas or physical laws.

Moving carefully and slowly, constantly in contact with convincing and well-established facts, from time to time we must allow ourselves to satisfy our desire to fantasize [68], remembering that information has a price, and the right information is priceless.

ACKNOWLEDGMENT

The author blesses the memory of Prof. Dr. E.I. Guigo and Prof. Dr. A.A. Guhman for their continued support during the development of the proposed idea.

ETHICAL APPROVAL

The author confirms that this study is not against the public interest, or that the release of information is allowed by legislation.

COMPETING INTERESTS

The author has declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

The author read and approved the final manuscript.

REFERENCES

1. Popper KR Objective Knowledge: An Evolutionary Approach. Oxford University Press, New York, 1979.
2. Lloyd S. Ultimate physical limits to computation. Nature. 2000:406:1047–1054.
3. Blum M, Vempala S. The complexity of human computation via a concrete model with an application to passwords. Proceedings of the National Academy of Sciences of the

United States of America 2020:1–8. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1073/pnas.1801839117.

4. Huang H. Comparison of three approaches for computing measurement uncertainties. Measurement. 2020:1-35. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1016/j.measurement.2020.107923.
5. Pavese F. Mathematical and statistical tools in metrological measurements. 2013:1-69. Accessed 5 August 2020. Available: https://www.researchgate.net/publication/259366249.
6. Porod W., Grondin RO, Ferry DK, Porod G. Dissipation in computation – Reply. Phys. Rev. Let*t*. 1984:52:1206–1206.
7. Norton JD. All shook up: Fluctuations, Maxwell's demon and the thermodynamics of Computation. Entropy. 2013:15:4432–4483.
8. Kish LB, Ferry DK. Information entropy and thermal entropy: apples and oranges. Journal of Computational Electronics. 2017:17(1):43–50. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1007/s10825-017-1044-1.
9. Brillouin L. Science and information theory. Dover, New York. 2004.
10. Hobson A. Concepts in Statistical Mechanics. New York: Gordon and Breach. 1971.
11. Bekenstein JD. Universal upper bound on the entropy-to-energy ratio for bounded systems. Phys. Rev. D. 1981:23:287–298.
12. Landauer R. The physical nature of information. Phys. Lett. A. 1996:217:188–193.
13. Srivastava YN, Vitiello G, Windom A. Quantum measurements, information and entropy production. International Journal of Modern Physics B. 1999:13(28):3369–3382. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1142/S0217979299003076.
14. 't Hooft G. Obstacles on the way towards the quantisation of space, time and matter and possible resolutions. Stud. Hist. Phil. Mod. Phys. 2001:32(2):157–180.
15. Ben-Naim A. A farewell to entropy: Statistical thermodynamics based on information. Singapore: World Scientific. 2008.
16. Zeng B, Chen X, Zhou D-L, Wen X-G. Quantum Information Meets Quantum Matter. Springer. 2018. Accessed 5 August 2020. Available: https://arxiv.org/pdf/1508.02595.pdf.
17. Vopson MM. The mass-energy-information equivalence principle. AIP Advances. 2019:9:1–4. Accessed 5 August 2020. Available: https://aip.scitation.org/doi/pdf/10.1063/1.5123794.
18. Burgin M. Information theory: a multifaceted model of information. Entropy. 2003:5(2): 146–160. Accessed 5 August 2020. Available: https://sci-hub.tw/10.3390/e5020146.
19. The BIG Bell Test Collaboration. Challenging local realism with human choices. Nature 2018:557:212–216.
20. Abramowitz M, Stegun IA., Handbook of Mathematical Functions. National Bureau of Standards Applied Mathematics Series – 55, Washington. 1964. Accessed 5 August 2020. Available: http://people.math.sfu.ca/~cbm/aands/frameindex.htm.
21. Burgin M. *Theory of Information:* Fundamentality, Diversity and Unification. University of California, Los Angeles, USA. 2003.
22. Del Santo Gisin FN. Physics without determinism: Alternative interpretations of classical Physics. Phys. Rev. A. 2019:100:1–9. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1103/PhysRevA.100.062107.
23. Shannon C. Communication in the presence of noise. Proc. IRE. 1949:37:10–21.
24. Baranger M. Chaos, complexity and entropy. 2001:1–17. Accessed 5 August 2020. Available: http://necsi.edu/projects/baranger/cce.pdf.
25. Kotelnikov VA. On the transmission capacity of 'ether' and wire in electro-communications, First All-Union Conf. Questions of Communications. 1933:1–23. Accessed 5 August 2020. Available: https://goo.gl/wKvBBs.
26. Bell S. A Beginner's Guide to Uncertainty of Measurement. 1999:1–41. National

Physical Laboratory, Teddington, Middlesex, United Kingdom. Accessed 5 August 2020. Available: https://www.dit.ie/media/physics/documents/GPG11.pdf.

27. Bose D, Wright MJ, Palmer GE. Uncertainty analysis of laminar aeroheating predictions for Mars entries. Journal of Thermophysics and Heat Transfer. 2006:20(4):652–662. Accessed 5 August 2020. Available: https://sci-hub.tw/10.2514/1.20993.
28. Golay MW, Seong PN, Manno VP. A measure of the difficulty of system diagnosis and its relationship to complexity. International Journal of General Systems. 1989:16(1):1–23. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1080/03081078908935060.
29. Piccinini G. Epistemic divergence and the publicity of scientific methods. Stud. Hist. Phil. Sci. 2003:34:597–612. Accessed 5 August 2020. Available: http://www.umsl.edu/~piccininig/Epistemic_Divergence_and_Publicity_of_Scientific_Methods.pdf.
30. Uzan J-P. The role of the (Planck) constants in physics. 2018. Accessed 5 August 2020. Available: https://www.bipm.org/utils/common/pdf/CGPM-2018/Presentation-CGPM26-Uzan.pdf.
31. British-American System of Units. Accessed 5 August 2020. Available: https://physics.info/system-english/.
32. Cgs system (2020). Accessed 5 August 2020. Available: https://www.maplesoft.com/support/help/AddOns/view.aspx?path=Units%2FCGS.
33. Mohr PJ. et al. Data and analysis for the CODATA 2017 special fundamental constants Adjustment. Metrologia. 2018:55:125–146. Accessed 5 August 2020. Available: https://iopscience.iop.org/article/10.1088/1681-7575/aa99bc/pdf.
34. Sonin AA. The Physical Basis of Dimensional Analysis, 2nd ed. Department of Mechanical Engineering, MIT, Cambridge. 2001. Accessed 5 August 2020. Available: http://web.mit.edu/2.25/www/pdf/DA_unified.pdf.
35. NIST Special Publication 330 (SP330), 2008, the International System of Units (SI). Accessed 5 August 2020. Available: https://www.nist.gov/pml/special-publication-330.
36. The International System of Units (SI) BIPM. 2019:1–218. Accessed 5 August 2020. Available: https://www.bipm.org/utils/common/pdf/si-brochure/SI-Brochure-9.pdf.
37. Jakulin, A. Symmetry and Information Theory. 2004:1–20. Accessed 5 August 2020. Available: https://goo.gl/QGBVoU.
38. Yarin, L. The Pi-Theorem. Springer-Verlag, Berlin, 2012. Accessed 5 August 2020. Available: https://goo.gl/dtNq3D.
39. Adamatzky A, et al. East-West paths to unconventional computing. Progress in Biophysics and Molecular Biology. 2017:8:1–84. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1016/j.pbiomolbio.2017.08.004.
40. Laszlo, A. Systematization of dimensionless quantities by group theory. International Journal of Heat and Mass Transfer. 1964:7(4):423–430.
41. Sedov LI. Similarity and Dimensional Methods in Mechanics, 10th ed., CRC Press. 1993.
42. Landsberg PT. Entropy and order. In: C. W. Kilmister (Ed.) Imbalance and Self-organization. Mathematics and its Applications. 1986:30:19–21. Springer, Dordrecht.
43. Schroeder MJ. An alternative to entropy in the measurement of information. Entropy. 2004:6:388–412, 2004. Accessed 5 August 2020. Available: https://goo.gl/vg8fk5.
44. Menin B. Hubble constant tension in terms of information approach. Physical Science International Journal. 2019:23(4):1–15. Accessed 5 August 2020. Available: https://doi.org/10.9734/psij/2019/v23i430165.
45. Taylor J. An Introduction to Error Analysis. University Science Books, Mill Valley, California. 1982.
46. Milton MJT, Possolo A. Trustworthy data underpin reproducible research. Nature Physics. 2020:16(2):117–119, 2020. Accessed 5 August 2020.

Available: https://sci-hub.tw/10.1038/s41567-019-0780-5.

[47] Chapman CA, et al. Games academics play and their consequences: how authorship, h-index and journal impact factors are shaping the future of academia. Proceedings of the Royal Society B: Biological Sciences. 2019:286:1–9, 2019. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1098/rspb.2019.2047.

48. Buchanan M. The certainty of uncertainty. Nature Physics. 2020:16(2):120–120. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1038/s41567-020-0786-z.
49. M. Baker. Is there a reproducibility crisis? Nature. 2017:533:452–454, 2017. Accessed 5 August 2020. Available: https://www.nature.com/news/polopoly_fs/1.19970!/menu/main/topColumns/topLeftColumn/pdf/533452a.pdf.
50. Freedman LP, Cockburn IM, Simcoe TS. The economics of reproducibility in preclinical Research. PLoS Biol. 2015:13(6):e1002165. Accessed 5 August 2020. Available: https://doi.org/10.1371/journal.pbio.1002165.
51. Ellis G, Silk J. Scientific method: Defend the integrity of physics. Nature. 2014:516(7531). Accessed 5 August 2020. Available: https://www.nature.com/news/scientific-method-defend-the-integrity-of-physics-1.16535.
52. Menin B. Uncertainty assessment of refrigeration equipment using an information Approach. Journal of Applied Mathematics and Physics. 2020:8(1):23–37. Accessed 5 August 2020. Available: https://www.scirp.org/journal/Paperabs.aspx?PaperID=97483.
53. Gavioso RM. A determination of the molar gas constant R by acoustic thermometry in helium. Metrologia. 2015:52:274–304. Accessed 5 August 2020. Available: http://sci-hub.tw/10.1088/0026-1394/52/5/S274.
54. Haddad D, et al. Measurement of the Planck constant at the National Institute of Standards and Technology from 2015 to 2017. Metrologia. 2017:54:633–641. Accessed 5 August 2020. Available: http://iopscience.iop.org/article/10.1088/1681-7575/aa7bf2/pdf.
55. Haensch T, Leschiutta S, Wallard A. Metrology and Fundamental Constants. IOS Press, Bologna Italy. 2007.
56. Willink R. Principles of probability and statistics for metrology. Metrologia. 2006:43:211–219, 2006.
57. Gödel K. Formally Undecidable Propositions of Principia Mathematica and Related Systems, 1931.
58. Pavese F. Analysis of current scientific data on climate and on their extrapolation beyond 2100. 2020:1–31. Accessed 5 August 2020. Available: https://www.researchgate.net/publication/339843361_On-Climate_F-Pavese_feb2020.
59. Falkovich G. Physical Nature of Information.2020:1–122. Accessed 5 August 2020. Available: https://www.weizmann.ac.il/complex/falkovich/sites/complex.falkovich/files/uploads/statphysII13.pdf.
60. Menin B. High accuracy when measuring physical constants: from the perspective of the information-theoretic approach. Journal of Applied Mathematics and Physics. 2020:8()5:861–887. Accessed 5 August 2020. Available: https://www.scirp.org/journal/paperabs.aspx?paperid=100314.
61. Pavese F. Replicated observations in metrology and testing: modeling repeated and non-repeated measurements. Accred. Qual. Assur. 2007:12:525–534. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1007/s00769-007-0303-4.
62. BIPM Guide to the Expression of the Uncertainty in Measurement (the GUM). 2008:1–134. Accessed 5 August 2020. Available: https://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf.
63. Pavese F. On the interpretation of systematic effects in metrology. Traceability to support CIPM MRA and other international agreements. 2008:1–8.

[64] Wheeler JA. Information, Physics, Quantum: The Search for Links, in: Complexity, Entropy and the Physics of Information, ed. W.H Zurek, Westview Press USA. 1990:3-28.

[65] Grégis F. On the meaning of measurement uncertainty. Measurement. 2018:133:41-46. Accessed 5 August 2020. Available: https://sci-hub.tw/10.1016/j.measurement.2018.09.073.

[66] Brumley LN, Kopp C, Korb KB. Cutting Through the Tangled Web: An Information-Theoretic Perspective on Information Warfare. Air Power Australia Analysis. 2012:2. Accessed 5 August 2020. Available: http://www.ausairpower.net/APA-2012-02.html.

[67] Sternlieb A. The principle of finiteness - a guideline for physical laws. Journal of Physics: Conference Series. 2013:437:012010:1-12. Accessed 5 August 2020. Available: https://www.sci-hub.tw/10.1088/1742-6596/437/1/012010.

[68] Linde A. Inflation, Quantum Cosmology and the Anthropic Principle. 2002:1-35. Accessed 5 August 2020. Available: https://arxiv.org/pdf/hep-th/0211048.pdf.