On the eve of the new leap in measurement science

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Abstract. At the beginning of the 21st century, the multidimensional problems of studying human and society have gone beyond separate sciences. As a result, the need for measuring properties (with providing measurement result traceability), which were considered immeasurable before, has increased. By performing cross-disciplinary and interdisciplinary investigations, to meet this requirement has become possible. In recent years, such investigations have received increased attention at the IMEKO congresses and symposia as well as other international congresses and conferences devoted to measurement science. Interaction in a creative team that consists of professionals in various scientific fields, development of common databases, work in the Internet on joint documents, etc. result in new problems. Organization difficulties concerning such investigations, capacities for overcoming them as well as the efficiency and features of collaborative work in a creative team, have been shown using the example of the experience obtained at the D.I. Mendeleyev Institute for Metrology.

1. Introduction

In recent decades, society life changes have resulted in appearing the new forecasts of civilization development. V. Voionich, Y. Harari, F. Fukuyama, R. Kurzweil, M. Kaku, and others can be mentioned among the authors of them. While analysing the projects of the near mankind future (i.e., in the 21st century) the question related to the future of science, which you deal with, in particular, measurement science, arises. The need for measurement science is determined by society requirements, its prospects depending on expected changes of these requirements.

At the beginning of this century, Maslow’s Hierarchy of Needs could become a benchmark for such a consideration. Maslow’s pyramid characterises the priority sequence of the society needs that originate as the society evolves.

The lowest levels comply with not only the mankind, but also animal populations. The first level of the hierarchy indicates that a necessary condition of any community development is the satisfaction of physiological needs guaranteeing survival.

After that, the priority moves to providing safety. At first, it concerns the desire of a subject to preserve his/her own life, then to secure a family or flock and to keep a status (for head or leader).

The 3rd level as a starting stage of socialization is characterized by the need for the sense of belonging to some community (it concerns love, friendship, or communication).

At the 4th level, the necessity of self-esteem, social recognition, and respect come to the forefront.
At the highest stage of development, society members come up with a self-actualization need that opens up perspectives of self-improvement.

The Hierarchy of Needs proposed by Maslow was repeatedly criticized, but a research carried out by Ed Diener in 2005-2010 and covered 155 countries, has demonstrated that the statistics confirm this concept [1]. Perhaps, the Maslow’s model is also efficient in the context of the forecasts for a few centuries. However, it is not enough for the near future analysis.

The pace of the technology development has increased dramatically. The Industry 4.0 revolution is coming. At present, some new trends have become predominating in a number of countries. These trends are likely to continue, at least, in the near future.

Observable changes are significant even in comparison with the end of the previous century. At present, in the International System of Quantities, all the base units of physical quantities are defined in terms of fundamental constants and determined with the help of quantum-mechanical standards. This fact demonstrates the technical opportunities to meet the requirements of most customers for measuring the base physical quantities with a required accuracy.

Links have increased between peoples living in different parts of the world. In many countries, the concepts of linguistic and socio-cultural identity have been updated. There is a need for methods to forecast the development of society based on measuring the parameters of new social processes, taking into account the inertia of the intercultural interaction consequences.

Due to the frequent changes of tasks being solved, in industry, the necessity has increased for specialists that are capable of self-learning throughout their careers. The society interest has grown in understanding, defying and quantitative evaluating of comparatively complex quantities characterising properties of human and society. The need has originated for internationally recognized evaluations of specialists’ knowledge and abilities, state of unhealthy people health and risks of its worsening, etc.

It should be noted that the necessity to measure the complex quantities of such a kind, is also implicitly associated with the 4th and 5th levels of the Maslow’s pyramid.

These tendencies become stronger due to the accelerated development of robotics. As a consequence, the problems related to the relationship between people and robots have originated.

Whereas K. Chapek [2] and I. Asimov [3] considered such aspects as the issues of the far future, in the course of Industry 4.0 epoch, these problems must be solved at the level of the mandatory requirements for software, which should be supported by international standards related to the ethical norms of robot behaviour.

However, if to evaluate any human or society property is necessary, it should be defined as a measurand and accompanied by definitional uncertainty. Such a quantity can be considered as multidimensional (multiparametric) one, e.g., tensor. In the simplest case, this quantity can be reduced to well-known measurands with the help of a justified mathematical relation, i.e., measurement model.

As a rule, this is a nontrivial task that requires involving knowledge from many scientific disciplines. At this stage, measurement science plays the role of the cognition theory basis [4] (i.e., “science of sciences” in accordance with [5]), and acquires a philosophical nature.

In this context, its important task includes definitions of properties, evaluation of which is required by society, development of measurement methods and models as well as corresponding measuring instruments.

The originated society requirement has led to the appearance of numerous papers in the field of theory and practice of multidimensional quantity measurements (see, e.g., [6-11]), including discussions on the problems of metrological comparability, compatibility, and traceability. (The references given in this paper are of an illustrative and, of course, not a definitive character.)

In recent years, metrological investigations aimed at measuring properties that were considered to be qualitative before, have received increased attention at IMEKO congresses and symposia as well as other international congresses and conferences devoted to measurement science.

However, in general, the spectrum of the research in this field is expanding slowly and does not keep up with the requirements of Industry 4.0 and Internet of Things.
The aim of the paper is explaining the reasons for the mismatch, justifying the actuality of such investigations, and analysing their performance experience with the emphasis on the opportunities to improve their efficiency.

2. Psychological aspects of complex quantity investigations

As it was explained above, the study of human and society is a large-scaled field where quantitative property estimations are the most actual. The investigations of the brain, human intelligence, perception of environment as well as formation of emotional assessment of a situation have become really a breakthrough direction. The concepts “image recognition”, “neural network”, “artificial intelligence”, “neuroeconomics”, “neurodidactics”, “machine learning”, “neurolinguistic programming”, and so on have become an essential part of our lives. However, very often, even the interpretation of these concepts is different for investigators working in various science fields.

Of course, a specialist can follow the recommendation of the Nobel Prize winner, academician P. Kapitsa that it is periodically worth changing the field of scientific activities [12]. Such a specialist can receive quite a good result combining knowledge and experience obtained earlier in some scientific field with the study of other ones. Such investigations can be called cross-disciplinary since they are characterised by the transfer of methods adopted in one scientific discipline to another.

However, in the opinion of the present paper authors, efficient results that open up the new prospects for science can only be achieved if the research is organized by a creative team that includes professionals from at least three different scientific disciplines. In accordance with [13], such studies are more correctly referred to as interdisciplinary. With regard to studying the properties of human and society, the team can include specialists who deal with psychology, biology, physiology, sociology, philology, mathematics, software, radio physics, measurement science, etc. Meanwhile, the team can consist of people coming from different organisations, cities, or countries and having different cultural and scientific backgrounds.

Certainly, the organisation of creative interaction, development of common databases, work in the Internet on joint documents, etc. result in new problems partly considered in actual book [14].

A few key problems can be singled out with regard to organisation of the teams researching in human and human related digital technologies [15].

The first one is the fact that currently, fundamental studies associated with some scientific discipline are poorly connected with applied scientific areas that are close. Most research focuses on specific hypotheses having experimental evidences, but related to local tasks that concern behaviour and activities of people.

The second problem is the weak transmission of fundamental knowledge between scientific disciplines. Scientific communications have some features such as fragmentation of scientific community based on activity spheres and scientific interests, organisation of scientific events related to specific themes or certain subject area as well as insufficient linkages between scientists working in various fields. These features do not enable prompt information-sharing important discoveries or significant achievements between professionals in various fields. As a result, discoveries in one field often remain “one science findings”.

Information that reaches the specialists in applied spheres, is of adapted or oversimplified character. Although information from fundamental fields somehow (by popularization or technologies) comes into practice, the opposite movement, i.e., request for studying topical problems of people, is comparatively weak.

The third problem is associated with different conceptual system, theoretical approaches, and methodology in various scientific fields. The examples related to human cognitive functions can demonstrate it. Speech research in psycholinguistic and cognitive investigations means obtaining the knowledge on specific category [16] or mental concept [17], very often having no clear connection with neuron mechanisms. However, in neurobiology, speech research is considered basing on neuroanatomic structures and neurophysiologic dynamics of cognitive processes in the brain [18].
Neurobiological interpretation of making decisions solely as the operation of comparatively independent brain systems chosen in the course of natural selection [19], from the psychological point of view, at least, seems strange and in some cases unacceptable. No psychological phenomena can directly correspond to the brain neuron activity even in case of considering specific zones that functionally relate to psychological processes, behaviour, or activities.

Psychologists consider concepts involving emotions (e.g., happiness, fear) as abstract ones [20]. The neurophysiological paradigm [21] interprets emotions as phenomena embodied in individual experience. Therefore, to investigate them by functional mapping of the brain activation patterns is possible. Such examples relate not only to the comparison of neurobiological and psychological studies. In particular, in education and psychology, processes of teaching and learning imply different content, in psychology and computer science, the notion of “intelligence” has different meaning, and so on.

The integrative resource of psychology [15] lies in the fact that it has common areas with various aspects. On the one hand, it concerns neuroscience, modelling and programming neural networks as well as measuring quantities concerning the complex kinds of psychological activities of people [22]. On the other hand, psychology is connected with applied fields such as economics, law, education, etc. that characterise interaction of society members. Psychology studies various phenomena that represent both consequences of the brain functions and reasons of activity efficiency, behaviour manifestation, as well as pathological states. It brings together various fields since it researches human as a multidimensional and multilevel system that is open and self-developing.

Without any doubt, the obvious advantage of cross- and interdisciplinary investigations is the most important factor that enables surmounting scientific fragmentation in the studies of human. To make the first steps in this direction, team members should be open to new knowledge, flexible, and tolerant. Initial requirements are mutual respect, strong desire to understand unfamiliar approaches to addressing problems as well as professional capability to find a compromise for achieving project goals.

To a significant extent, emerging communication problems in a creative team aimed at solving tasks related to measurements of complex quantities are associated with the T. Kuhn’s paradigm shift. Many professionals, who have high scientific reputation due to the achievements in some narrow traditional fields, do not want to waste efforts on additional education. At the same time, they are unconsciously afraid that work in a new sphere can lead to downgrading their status because of participation in a risky project. They try to resist the deviation from the conventional approaches.

The mentioned reasons exacerbate the organization of a creative team. To overcome these difficulties, it is necessary to form the interest in investigations being carried out as well as comprehension that the results will stimulate a number of new research directions and applied developments including those linked with previous experience and accumulated knowledge. A significant role in creating such atmosphere can be played by extraordinary individuals included in the team. Risky investigations, as a rule, attract attention of such people.

Thus, in the opinion of the authors, the success of interdisciplinary research is facilitated by the obligatory forming a certain core of a creative team. It should include specialists in the field of measurement science who, as explained in Section 1, will ensure the development of effective models and methods of measurement, as well as psychologists. The core of the creative team should also include specialists in mathematics and software. Their role is determined by the need for automatic recognition of the multidimensional measurands.

In the light of the foregoing, at present, it is very important, basing on the experience of cross- and interdisciplinary investigations, to prove their efficiency, discover their features, and show prospects that their results can open up.

3. The experience of cross-disciplinary and interdisciplinary investigations
In the first decade of the 21th century, the European programme under the catchy name “Measuring the Impossible” Network has become the greatest stage in the field of complex quantity investigations. These works have required joining efforts of experts in measurement science, psychology, physiology, music, and others [23, 24].

The strategic task of the programme was to stimulate cross- and interdisciplinary studies aimed at searching methods and developing instruments that will be able to provide quantitative estimations of properties (nominal properties) especially related to the brain functioning, that before had been defined as immeasurable [25]. This should enable improving the efficiency of the most significant studies in the foreseeable future.

Among actual tasks included in the programme, in particular, there were fundamental investigations focused on the development of measurement models that enable quantitatively estimating unexplored processes characterising human. In particular, among them, there are:

• short-term distortions of space and time perception related to the interpretation of the surrounding world;

• comprehension of gained experience, formation of self-consciousness as well as understanding the behaviour of another person;

• emotions and feelings originating while listening to music;

• perception of sensory information transmitted by the nerve cells in human’s eyes and skin.

In recent years, interest in human properties has manifested itself also in applied investigations aimed at developing “artificial nose”, “artificial tongue” [26], and “artificial finger” [27]. These instruments should contribute to increasing the diversity of competitive food products, perfumery, artificial materials that mimic natural ones, etc. The need for automatic diagnostics not only organism diseases, but predisposition to them, has formed [28, 29].

A number of specific applied works was presented at the TC1-TC7-TC13-TC18 IMEKO Symposium that was organized in Saint-Petersburg, Russia, by the D.I. Mendeleyev Institute for Metrology. The Symposium motto was “The future glimmers long before it comes to be”. Let us cite some examples.

Lyubimtsev et al. in [30], present a work carried out jointly by biologists, engineers, and an expert in metrology. After fulfilling complex studies, the authors have developed a measuring system with crayfish as biosensors, which is applied for water quality evaluation.

The cross-disciplinary investigation conducted by experts in measurements and medicine [31] has resulted in the development of the novel approach to upper limb biomechanics evaluation. The basis of the method is fixation of movement elements, which is demonstrated using a daily life gesture such as drinking. The study of healthy testees and patients with injured upper limb have proved that the proposed approach can be useful for supporting upper limb treatment.

A team including linguists and experts in measurements (in particular, psychometrics), proposes application of a new method of linguistic meaning explication called Natural Semantic Metalanguage [32]. At present, it employs 65 universal words (primes). On the one hand, they cannot be decomposed into any simpler terms, on the other hand, the meanings of them are invariant in various languages. A more complicated meaning can be explained at a simpler level up to reducing to primes. The authors show the possibilities of synergy between the measurement and linguistic theory.

At the above-mentioned Symposium, some papers can be singled out, related to fundamental aspects. In particular, Kneller and Fayans in [33] propose an approach to interdisciplinary problem identification and systematisation of the methods for addressing them. Hereby, a step has been made to develop a universal algorithm of solving interdisciplinary tasks.

In Russia, investigations in the field of developing measurement models intended for the analysis of neurophysiological and social processes have been being carried out at the leading metrological organisation D. I. Mendeleyev Institute for Metrology, St. Petersburg, that has the status of the State Research Centre. In the view of the authors of the present paper, the experience of the performed studies is typical of cross- and interdisciplinary investigations.

At first, the research concerning the measurement of human and society properties was carried out proactively (for free) together with enthusiastic humanitarian specialists from other organisations. At that stage, the group singled out investigation directions and prepared the first publications, in particular [34]. As a result, the core of the creative team has been formed. Then, partly basing on a state grant, under the supervision of the authors, the team has been established that consisted of highly qualified neurophysiologists, psychologists, musicologists, mathematicians, programmers, and philologists.
The team has justified the model intended for measuring expected emotions as a response to acoustic impacts. An important feature of this model is as follows: it also reflects the structure of the corresponding mechanism of forming neurophysiological processes related to the origination of emotional responses to acoustic signals. Definitely, corresponding acoustic signal should have a certain emotional “colour”. The model links certain soundings with the brain biorhythms characteristic for emotions (figure 1 and figure 2).

![Figure 1](image1.png)

**Figure 1.** The first step of measurement model [35].

![Figure 2](image2.png)

**Figure 2.** Three-steps measurement model [35].

The most significant part of the model (figure 1) includes a joint nonlinear converter and selector of infrasound oscillations. The former one converts an input acoustic signal together with the same signal but 0.15-0.3 s delayed. The selector separates infrasound oscillations and divides them into biorhythm zones that are specific for basic emotions. Then, corresponding oscillations in a normalized form enter a comparison and recognition unit [35].

The model provides an opportunity to analyse the emotional “colour” of music fragments and reveal their features, including those that are characteristic for classical music, bell rings as well as ethnic drum compositions [35, 36]. The results will make it possible to develop qualitatively novel measurement instruments which will help composers and performers to understand the specificity of music perception in various countries.

At present, investigations concerning quantitative analysis of the music performance features and listeners’ perception of these features are in progress.

After the structural blocks of the model had been theoretically linked with a certain parts of the brain, the model gave an opportunity to explain statistic data concerning the longevity of conductors and musically gifted actors as well as scientists taking great interest in their research and loving music.

The longevity reason concerns the influence of regular intensive emotional excitation. The point is that emotional reactions causing an impulse electric field in the limbic-reticular complex of the brain
affect another part of this complex located closely, which controls basic physiological functions. If these impacts are accompanied by physical loads that are typical, e.g., for conductor and actor activities, their physiological systems are trained regularly. As a result, their state of health improves [35].

The same mechanism clarifies the correlation between the “tarnish” of emotional perception of life and health deterioration. The thing is that the positive effect of the emotional excitement impact decreases, partly because of hearing disabilities related to age.

The model possibilities enabled also starting the development of a special musical tune that can provide greater expressiveness of instrument soundings, i.e., clearer reproduction of emotional “colour”, by automatic control of tuning in the course of playing musical compositions.

The opportunity to determine objectively (using a measuring instrument) the emotional content of music fragments gave the cause to apply special musical excerpts in medical practice. The hypothesis was put forward that music causing disturbing emotions should lead to inner organism stress. An experiment related to automatic medical diagnostics based on the features of cardio impulse sequences [28, 29] was performed together with Prof. Uspermskiy, a medical doctor of a wide profile. The experiment has demonstrated that listening to anxious ethnic music (even if a testee is distracted by solving logic tasks) enables taking into consideration a greater number of factors and, as a result, revealing the predisposition to some diseases.

An analysis showed the proposed measurement model is reversible. Since the first step of the initial model demonstrates the mechanism of biorhythm formation related to certain emotions as a result of characteristic acoustic signals, the hypothesis was put forward that an inverse model of the first step reflects the mechanism of acoustic signal origination as a reaction to certain emotions. The idea that the model is reversible allowed determining new directions of investigations:

- improvement of automatic interpretation quality through consideration of emotional capacities of speech fragments [37];
- automatic interpretation of animals’ language, “vocabulary” of which is determined by a limited set of basic emotions and their simplest combinations [38, 39].

The inverse model gave rise to the method enabling diagnosing the deviations of babies’ brain development by the analysis of their vocalisations in the course of the first weeks and months of life. It is significant that such a diagnostic testing does not require any impact on a baby and can be performed remotely, e.g., by using audio records made by baby’s parents at home.

A pilot investigation [35] has shown that as babies grow up, the changes of vocalisation spectrums obtained after nonlinear conversion open up the prospect to diagnose autism and other brain disorders at an early stage. Using traditional methods, they are diagnosed much later (sometimes, around the age of 2 years). Therefore, it becomes possible to develop treatment methods at the stage of high flexibility of the brain, when the probability of success is significantly greater.

The approach being proposed also gives grounds to work on the problem of revealing positive deviations in the baby’s brain development (his/her emotional talent). As a result, the basis for development of noninvasive methods of impact on the brain can be created, which will be able to contribute to strengthening the competitiveness of humans in comparison with robots.

According to Russian academician E. Kreps’s words [40], “if the Nature has found a reasonable solution to a biological problem, it will apply this solution in the process of further evolution”. In other words, provided that in the course of evolution, some action sequence was successful (i.e., in the event of originating serious difficulties, it has resulted in founding a new development way), as a rule, the similar sequence of actions is applied to break an analogical impasse at the later stages of development.

Comprehension of this regularity facilitates the formation of efficient measurement models related to cross- and interdisciplinary investigations.

Typical example: to provide prompt adaptation of animal populations to changing environment, in the evolution process, the limited number of signals (basic emotions) and possibility to provide their long-distance transmission and reception have originated. Accordingly, the variation analysis of signal sets carrying basic emotions of babies as well as elderly people can be employed for their diagnostics.
To reach the same purpose, in [31] the set of movement elements related to upper limbs is used. Similar approach can be revealed in [32], where complicated meanings in linguistics are explicated by reducing them to the set of primes.

Given examples indicate that measurement models based on solutions that were found in the evolution process, can be very efficient. It was just this concept that stimulated the authors of this paper to conduct some interdisciplinary investigations in the field of measurement science, history, and sociology. The L. Harrison’s book [41] and some others associated with it, have become a stimulus for them. A concept of a specific social process “mechanism” proposed in [4] gives hope for mathematic description of some regularities concerning civilisation development in both the past and future.

4. Conclusions

The coming industrial revolution has caused the increased interest in studying the properties of human and society. The consequences of the coronavirus pandemic have further intensified this interest, which requires expanding the practice of cross- and interdisciplinary investigations.

The understanding of their organization peculiarities discussed in the paper as well as the role of experts in measurement science and psychologists in a creative team should contribute to the increase of their effectiveness, especially, at the stage of developing measurement models. The experience has shown that the most promising are measurement models that correspond to the models of “mechanisms” forming cognitive, physiological, or social processes.

Measuring the properties of human and society not only extends the range of tasks that measurement science has to perform, but also dramatically tightens up the requirements for the training of relevant specialists.

Working in the field of measurement science will require developed associative thinking and great erudition. Young people should be prepared to meet these requirements.

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