Introduction to the Methodology of Science

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Edition Cognitive Studies

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Introduction

Philosophical reflexion of the methodology of science focuses on the problem of the science nature, problem of science method and problem of scientific thinking. Scientific rationality is characterized by its generalizing approach which does not emerge from individual subjective experience but inter–subjectively repeated and communicated experience. This represents the primary base of data (facts) that are further analysed and explained by exactly defined method (accurate series of steps).

With regard to enormous methodological diversity of various sciences, to write an introduction to methodology of science is almost an impossible task. Therefore, it is necessary to focus on a specific aspect, individual perspective from which the methodological problem can be analyzed. The presented text focuses in the first place on the so–called *general scientific methods* that are related to higher cognitive processes such as generalization, abstraction, deduction, induction, analogy, analysis, synthesis and other. These mental processes are necessarily used within methodology of all scientific fields because they directly condition the possibility of scientific explanation of the monitored phenomena, hypotheses formation, interferences, theories, creation of different types of models and experiments, formation of proofs (hypotheses confirmation) or deriving of theoretical predictions. From this perspective also the individual chapters of Introduction to the Methodology of Science are organised, from the basic general definition of the science and scientific method phenomenon to the specification of scientific procedures within the research in social sciences.

The presented methods represent mutual methodological platform based on which it is possible to elaborate some currently very important inter–scientific research (e.g. cognitive sciences). The basis of these interdisciplinary approaches connecting different kinds of formal, natural, liberal or social sciences, is the process from (1) phenomenon or group of phenomena observation and description, through (2) formation of testable hypotheses that should explain the discovered phenomenon based on the causality principle, to (3) verification of hypothesis validity (mostly based on its predictive power) and (5) its potential integration into the system of other confirmed premises and general laws.

The basic goal of the world scientific recognition is to present the explanation of the complex of related observation of events, based on confirmed hypothesis and multiple–verified by independent researchers groups.

1. General Definition of Science

Keywords: *science, scientific knowledge, scientific method, scientific realism*

1.1 Introduction

> *"Scientific method in itself would not lead anywhere; it would not even come into being without the ardent endeavours to understand."*
>
> (A. Einstein)

It is very difficult to describe the phenomenon of science and gaining of scientific knowledge in general, yet it is even more difficult to explain them. However it is certain that in modern society scientific cognition of reality notes remarkable success and is the source of many audacious expectations. The basis of effective scientific rationality is exactness of methods to which it is interconnected. To view scientific method as one of the basic problems of philosophy was pointed out by René Descartes as early as the 17th century. He first focused his attention on studying methods of logics, algebra and geometry. On their basis he tried to establish the four basic rules of a new universal method. The first one was related to the necessity to keep evidence of accepting claims about the state of matters — with importance on the clarity and distinctness of these statements.

The second rule defines the necessity to analyse issues under examination. The third rule defines the succession from simple and most easily recognised to the more complex and less clear. The last rule refers to stating complete calculation and analysis overviews so that we can be sure that we have not forgotten anything (Descartes, 1992). In the same way the methodology of modern science (even though it is most problematic to understand scientific method as a whole) is primarily based on the requirements of clarity, easy grasp, evidence and hierarchical succession from simple to complex. Explication of these terms being the subject of philosophical and scientific methodology is very demanding.

> The philosophical analysis of scientific methodology is primarily a deductive 'meta–science' which studies science with regard to its structure and methods, it analyses the character of scientific explanation, the means of scientific classification and systemization of reality, possibilities and boundaries of scientific objectivity and the evidence of scientific knowledge.

1.2 Basic Characteristics of Science and Scientific Reasoning

The basic problem of methodology of science is the problem that stems from the nature of science, the problem of scientific method and the problem of scientific reasoning. The nature of science is a subject to many philosophical debates. With scientific reasoning a certain type of reliability is connected. This reliability is guaranteed by the specific method employed by science. Science is usually characterized as a system of scientific knowledge which depicts natural relations of objective reality and which is used to explain, predict and change reality. The main features of science as a system of knowledge are:

scientific method — empirical process of discovery and demonstration which is necessary in scientific investigation. Mostly it includes observation of the phenomenon, stating a hypothesis about the observed phenomenon, a set of experiments that confirm or disprove stated hypotheses, and a definition of conclusions which confirm, falsify or modify the hypothesis. Scientists use the scientific method to define the relation between cause and effect in nature. They follow the principle of observation — prediction — testing — generalization;

— structure — strictly defined inner bonds and structures;
— language — an exact system of expression;
— critical thinking — scientific knowledge is a subject to the constant process of falsification, definition of conclusions in form of laws, which are (criterions of validity being strictly stated) generally valid;

Theoretical scientific knowledge has:

— general character
— systematic character
— explanative function
— predictive function
— critical character
— objective character (it fulfils the condition of inter–subjective verifiability and provability),
— exact character
— undergoes development

Scientific rationality is thus characterized by its generalizing approach, which does not stem from a singular subjective occurrence, but from an inter–subjective repeatable experience. This represents the fundamental basis of empirical data, which are further examined and explained by a strictly defined exact method (often using mathematical descriptions). Another feature of scientific rationality is the effort to create a systematic unity. In this sense, one of the first scientists is Aristotle who refined classification of knowledge and divided science into theoretical, practical and formal sciences. Scientific explanation is of a theoretically — explanative character. The essence of science is not in describing phenomena but in explaining them and thus justifying them. Scientific thinking is characterized as a thought process applied in science, which encompasses cognitive processes of theoretical generalization, designing experiments, testing hypotheses, data interpretation and scientific discovery. Scientific thinking is constituted based on inductive or deductive operations, on the principles of analogies, abstraction and idealization. It stems from the principle of deterministic world set–up, from the principle of causality. Causality is a relationship between two time–bound simultaneous or consecutive events where the first event (cause) sets off the second event (effect). In the case of a causal relation the rule is that when one event occurs, it consequently produces, causes, or determines the second event. If the same event occurs again, (inevitably) the second one must appear.

Scientific explanation is a set of statements which explain the existence or occurrence of objects, events or the state of matters. The most frequent forms of explanation are causal explanation, deductive — nomological explanation, which means including an explanandum (the object of explanation), from which an argument can be deducted (e.g. 'All gases expand when heated.' This gas is being heated. This gas is expanding.'), and statistic explanation, which means including an explanandum in the general statement, which is formulated on the principal of induction (e.g. 'Majority of people who smoke tobacco get cancer.' This person smokes tobacco. This person gets cancer.).

Scientific method in general is described in several basic steps:

1. Phenomenon or group of phenomena observation and description.
2. Hypothesis formation which should explain the discovered phenomenon on the basis of causality principle.
3. Hypothesis validity is tested in various ways, while the level of formed hypothesis predictive power is important. Based on the

hypothesis predictions, the experimental tests are consequently created (mostly in case of natural sciences), which are supposed to confirm (corroborate) or disprove (falsify)the hypothesis.
4. In the last step, the multi–times verified hypothesis is integrated into the system of other confirmed assumptions and general principles of scientific theories. Scientific theory is the explanation of the related observations and set of events based on confirmed hypothesis and multiple–times verified by independent groups of researchers.

Such model of scientific exploration originates firstly from the inductive derivation principle. Induction is a process of derivation of individual facts and cases from general principles. It is a form of argumentation, which advances from empiric premises to empiric conclusions, while the conclusions are not able to be directly derived by deduction from these premises. Hence inductive arguments are a form of equitable argument, in which based on the principle of probability it is derived more than it is included in its premises. Premises are the base of conclusion. However, the conclusion does not necessarily result from them.

In the most general sense the sciences can be divided according to their subject of exploration to:

— realistic — natural, liberal and social,
— formal — mathematical — logical
— Realistic sciences are usually divided into:
— nomothetic — they search general, causally explicable quantitative laws (primarily natural sciences);
— idiographic — they describe original events, e.g. explanation of historic events, interpretation of texts (primarily liberal sciences).
— In terms of science subject of exploration, the sciences are divided into:
— theoretical (fundamental),
— practical (applied).

1.3 The Problem of Scientific Realism

At the beginning of the 20th century, a neo–positivistic trend was developing within the philosophy of science with the main focus on the reasoning of objective character of scientific statements about the universe. The emphasis was put mostly on the methodological conditions of the objective science possibility, the criterion of reliability and truth was being searched. Neo–positivistic paradigm was based on postulating of primary empiric nature of science, while observation and experiment was supposed to be the basis of scientific methodology. The pilot material of scientific examination was the observable data formed as protocol sentences (in a form of laboratory protocols). Those had to meet the requirement of objectivity (independence on the subject which they observe) and were supposed to become the criterion of validity for other scientific statements. Protocol sentences state the facts which precede any statement about the universe. Therefore, they are at the beginning of scientific examination. „I consider this a significant improvement of the method that researchers in order to get to the basis of knowledge did not look for the primary facts, but primary sentences", (M. Schlick, 1968, p. 242). The criterion of knowledge validity is in further phases moved from individual protocol sentences to mutual relation of noncontradictoriness of protocol sentences (transition from correspondence). The validity of knowledge is given by the mutual agreement of protocol sentences. Every individual protocol sentence is rectifiable.

This phase of conceptualisation of science and scientific method determined the so–called *the Given* (from German das Gegebene) to be the basis. It is possible only to refer to "the Given", not question the nature of its existence. This question does not have any empiric significance, and therefore it exceeds the limits of scientific explanation of the universe. R. Carnap defines their principled verifiability as the basic criterion of scientific statements. He refers to the so–called perceptive statements, which are the condition of the verification possibility. The significance of statements is directly related to the possibility of deducing the perceptive statement from this statement. On the contrary, metaphysical statements are related to the realities, which cannot be reduced to perceptive statements. This is knowledge about something that is above or beyond any experience. Hence, experience (in terms of primary empiric experience) is the criterion of significance, objectivity and the condition of verification possibility. The criterion of scientific statements character is the principled possibility to deduce perceptive statements from it. The question of the real existence of the universe according to Carnap is deprived of any significance because it is without a relation to the perceptive experience. The scientific cognition is separated on the background of metaphysical problems, while the significance and meaning is linked to the possibility of empiric verification. Metaphysical statements have only expressive function similar to the arts. In reality they represent nothing; they are not related to anything. Neo–positivists refer to Hume's thoughts on principled unverifiability of the fact of existence, while the only subjects of potential verification are the quantitative relations.

In this regard, however, there is the question of the degree of the perceptive data objectivity as somewhat "raw material" of scientific explication. Subjective aspects of perceptive experience related to various perceptive illusions, perception deformation, emotional states perception deformation, incorrectly performed observations and experiments. More detailed analysis of empiric "given" invades the original certainty of objective character of the perceived. This topic will be discussed in the chapter called Observation.

Within the current understanding of science, there is still bigger emphasis put on the creative task of reasonability while forming the hypotheses and scientific theories which exceeds the boundaries of observed phenomena description. There is a transition from the passive recording of protocol sentences to active formation of empiric experience in a form of various experiments, devices and computing technology. Accuracy, mathematization and scientific terminology are characteristic for the language of science.

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2. Scientific Explanation

Keywords: *scientific explanation, Deductive–nomological model, scientific law, inductive–statistical model, statistical relevance model*

2.1 Introduction

One of the fundamental issues related to the nature of science is the question of the nature of scientific explanation. What makes scientific explanation different from a simple description? Alternatively, what type of explanation is characteristic for scientific theory? There is not only one model of scientific explanation within the theory of science.

Currently, two different alternatives regarding the nature of explanation are being elaborated. The first alternative describes the explanation as an argument, in which the explicated phenomenon logically follows from the well–established premises. The first premise is in the form of natural law (either universal or statistical–probabilistic) and the second premise is an acknowledgement of the initial conditions, description of the phenomenon, obtained by observation. The most famous alternative of the argumentation nature of explanation is the deductive–nomological model (DN) developed by Carl Hempel. Another type is the inductive–statistical model of explanation. The second alternative of the nature of scientific explanation defines explanation as a sort of reconstruction of the causes of an observed phenomenon. In this method of explanation it is not necessary to refer to the existence of natural laws, but it deals with the specification of causal mechanisms, causal history of explananda. This type of explanation was elaborated especially by W. Salmon as so–called ontic explanation.

Different models of explanation serve a variety of explanations of the nature of differences between explanation and description.

> The basic structure of every explication is the relation between the explained (explicandum) and the explaining (explanans). The essential is the acknowledgement of a lasting relationship between explicandum and explicans that can be applied with a high degree of probability (or necessarily, in case of deductive arguments) and therefore has considerable predictive power.

The result of scientific explanation is the acknowledgement of certain regularities, certain types of uniform relations.

2.2 Deductive–Nomological Model

Within the deductive–nomological model of explanation (DN model) C. Hempel distinguishes two types of explicatory facts: (1) individual facts and (2) uniformities expressed in form of general laws. Explanation takes the form of deductive argument:

$$\frac{\begin{array}{c}C1,C2,\ldots,Ck\\ L1,L2,\ldots,Lk\end{array}}{E}$$

where C1, C2, ..., Ck are statements that describe various events or facts which we refer to; L1, L2, ..., Lk are general laws. These components constitute explanans. Conclusion E is a statement that describes the explanandum; it is the explained statement (explanandum–statement). The essence of the argument is based in the deductive explananda subsumed under certain general patterns, which have characteristics of laws. DN model provides an answer to the question, why the same event (explanadum) occurred by showing how this incident resulted from various circumstances (C1, C2, ..., Ck) in accordance with the general laws (L1, L2, ..., Lk) (Hempel, 1962). This method of scientific explanation is therefore based on the deductive thought processes and the existence of universal laws ascertaining some degree of uniformity in nature.

The concept of natural law within the philosophy of science is the subject of many controversial debates, as it is missing a clear statement of its nature, the criteria that distinguish laws from statements, which are not laws.

2.3 Scientific Laws

In relation to scientific laws E. Mach and G. Kirchhoff defined a basic postulate — they should be formulated not to consider the question of *why*, but to answer the question of *how*. Scientific law should contain nothing else than the sum of the observed generalizations about the properties of the examined phenomenon. The law in science is an abridged and condensed report on experimental observations. The relationship between a set of experimental observations and the law, which is established by them, has the nature of the inevitable resulting. There is only one direct path from a set of observations through an ascertainment of patterns to a scientific theory. This method of scientific explanation is similar to the method of determining the average height of a class of students by averaging the measured values of the heights of all students in this class.

According to C. Hempel, laws of nature are empirical generalizations that connect different aspects of observable phenomena. Laws have a certain degree of explanatory power; they answer the question *why* by subsuming the identified uniformities under laws with a wider extension. So the laws formulated by Kepler and Galileo are reasoned as special cases of Newtonian laws of motion and gravity, and these are in turn explained by their subsuming under the more general laws of general relativity.

R. Carnap provides two central values of scientific laws — explication and prediction. For example, Driesch's theory of entelechy examines the difference between law and "pseudo–law". H. Driesch formulated the theory of entelechy as a specific force that causes living organisms to behave in a certain manner. Entelechy, however, cannot be understood as physical force, because physical force is not an adequate explanation of the functioning of living organisms. Entelechy is not set in space, because it does not affect individual and separate areas of the body, but affects the body as a whole. It is similar to magnetic or gravitational force, which themselves are also not visible. According to Driesch, the concept of entelechy had the explanatory power of a natural law. By this example Carnap demonstrates what the characteristics of a valid scientific law are: There must be criteria of law validity (for example, when "entelechy" would be strengthened and when it would be weakened); certain predictions must result from the law, by which it would be possible to verify its validity. Also, the law must be in a certain relation to the whole corpus of existing valid laws (Carnap, 1966). Similarly, J. S. Mill observes: "The concept of empirical law contains the implication that it is not the ultimate law, that its validity must be constantly re–examined. It is a derived law, whose origin is not yet known. If we want to formulate an explanation, the answer to the question *why* in the form of an empirical law, we would have to determine what the law was derived from in order to determine the final cause, on which it is dependent. And if we knew it, we should also know, what are its limits and under what conditions it would no longer apply" (Mill, 1950, p. 270).

The problem of distinguishing between real law and random regularity proves to be crucial in the context of the application of the DN model. So what is the most essential characteristic that

constitutes a scientific law? There is a number of criteria regarding the "authenticity" of a law: 1. it must be a generalization, leaving no exceptions, 2. it must contain purely qualitative predicates and may not apply to individual objects or space–time locations, 3. it must withstand various thought experiments, 4. it must be integrated into the body of systematic theory and play a unifying role in scientific explanation (Machamer, 2002).

2.4 Alternative Explanatory Models

Within the deductive–nomological model the explanation has the nature of argument, where the explanandum is an expectable case of explanans. In other words — explanandum with deductive certainty results from the explanans. Hempel reflected on the fact that many explanations in science have more statistical than deterministic character. Therefore, he proposed a model of inductive–statistical explanation (IS). Statistical laws explain individual cases by suggesting their high probability. For example, in a statistical law, which states that every person exposed to measles virus (V) has a probability of being infected with measles at 0.8 (S). If a particular person who comes into contact with the virus and develops the disease (C), we are able, according to IS explanatory model, to explain this phenomenon as follows: C results from a combination of V and S, because this combination represents a high probability of C. The IS explanatory model is thus an inductive analogy of the DN explanation, because the IS notes that the explanandum with a high probability (not a necessity) results from explanans premises, which are relevant laws and initial conditions (Psillos, 2008).

W. Salmon, however, points to the existence of the so–called explanatory irrelevances, which are beyond the possibility of explication by the IS model. He includes the following example:

(L) All men who regularly use contraception do not become pregnant.

(K) John Johnes is a man who uses contraception regularly.

(E) John Johnes does not become pregnant (Salmon, 1971).

On the basis of these examples, many have questioned whether the DN/IS model provides sufficient conditions for the explanation. The problem of causality appears here, determining the effective causes of phenomena (what causes what). In the context of these objections the explanatory model of statistical relevance (SR) has been developed. It is based on the following arguments:

— explanation must follow the principles of statistical relevance and relations of conditional dependence;
— if there is a group or population A, attribute C is statistically relevant to attribute B if and only if P(B/A.C) is not equal to P(B/A) — that is, if and only if the probability that B is subject to A and C, is different from the probability that B is subject only to A;
— explanatory power has only statistically relevant properties (or information about statistically relevant relationships (Salmon, 1971).

Criticism of the DN explanatory model also applies to its ambition to provide explanations of phenomena in form of deductive arguments that are inevitably valid. Indeed, there are arguments that take the form of a DN explanation, but they incorrectly set the effective cause of the phenomenon. For example, to explain the length of the flag pole the explanation must be based on the premise of the length of the shadow of the flag and assumptions about the physical laws of optics. Such an explanation says nothing about why the flag pole is of a certain length.

W. Salmon distinguishes three approaches to scientific explanation, which he named as epistemic concept, modal concept and ontic concept (Salmon, 1984). Hempel's deductive–nomological model is an epistemic concept. Especially important is the epistemic aspect of explanation that results from relying on the law and its inevitable consequences. Modal approach differs from epistemic mainly in explaining the inevitable — explanandum necessarily results from explanans in such a way that it is not possible for it not to occur if relevant laws of nature apply. In case of ontic version of

explanation, the essential postulate is its close interconnection to causality.

Therefore, Salmon reworked the model of statistical relevance and developed the causal–mechanical model (CM), which goes further than the acknowledgement of statistical and relevant relationships within the SR model and is based on a determination of causal relationships of explicative phenomena. The CM model is based on several basic postulates:

— causal process is a physical process (e.g.: movement of a ball in space),
— this process is characterized by the ability to transfer certain features,
— causal processes have the ability to continuously spread their own structure from place to place and time without further interference from the external environment.

The introduction of a scientific explanation is therefore a demonstration of how events fit into the causal structure of the world. W. Salmon understands explanation as a process through which explanands are located in their respective places within the existing causal structure of the world. In Salmon's ontic conception the causal relations are primary towards explanatory dependence relations. The method of interpreting these phenomena "parasitizes" on their causal determinations (Salmon 1984).

In addition to the mentioned concepts of scientific explanations, there is a variety of others — such as the unifying model of explaining that understands the process of explanation as a demonstration of how a certain fact can be derived from a unified set of argumentation schemes (basic principles, such as axioms, theorems, etc.). To explain a certain fact therefore is to show how it can be incorporated into a single theory. It is important to demonstrate its relationship to other facts that theory explicates.

Another type of explanation is a probabilistic model, which is based on the postulate that the explanation depends on the context (e.g.: from the knowledge of the author of explanation, and the purpose of explanation, etc.). There is therefore not only one perfect explanation, but merely an explanation determined and limited by different determinants.

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3. Scientific Theories

Keywords: *scientific theory, observational term, theoretical term, inter–theoretic reduction*

3.1 Introduction

An important problem in the case of scientific explanation is the nature of the relationship between explanand and explanans. In the case of scientific theories, the problems are opportunities of the theory to represent the empirical content. E. Mach held a view that scientific theory must derive its existence primarily from the phenomena that it is meant to explain. Within the framework of logical positivism, the primary function of logic as a criterion of cognition veracity and observational statements that formed the basis of knowledge, were considered the pillars of scientific theory. Other concepts of the theory of science consider a model, in which empirically observed phenomena can be described, as a basis for a scientific theory.

The fundamental question remains, however, what role scientific theories should possess, for what purpose they should be formulated. Is it merely a set–up of certain formalized set of laws, through which one is able to understand different aspects of empirical reality in a systematic framework to formulate specific predictions and gain control over outside course of events? Or is the goal of scientific theory to explain the deeper causal relationships that are not accessible to a direct observation? In other words, are scientific theories only different types of description or do they proceed beyond the immediate empirical experience?

3.2 Scientific Theories Structure

In the intentions of the concept of syntactic structure of a scientific theory is the theory of empirically interpreted axiomatic deductive system. This concept is also known as the "received view" (Putnam), hypothetic–deductive approach (Lloyd), propositional explanation (Churchland). Two types of non logical terms may be identified within this concept: observational terms (e.g.: red, touch, bar, etc.) and theoretical terms (electron, gene, fields, conductivity, etc.).

Observational terms depict objects that are publicly observable and determine the quality of the observed objects. Theoretical terms correspond to the remaining, generally unobservable, qualities and objects. Similarly, there are two types of statements in science — observational and theoretical statements. Observational statements contain only observational terms and logical concepts; theoretical statements consist of theoretical terms. Scientific theory is considered an axiomatic system that is initially un–interpreted and acquires an empirical significance (meaning) specifying the meaning of observational terms (Nagel, 1962). According to R. Carnap, a theoretical system represents a nun–interpreted system of postulates. A theoretical term is interpreted by using correspondence rules together with an observational term. Theoretical term acquires its empirical significance, its reasonableness, if it is possible to derive from a theoretical postulate that includes this term such a prediction of observable events that could not be derived from the statement that does not contain this theoretical term. A statement that includes observational term O (So) is logically

implied by the conjunction of the statement containing theoretical term M (Sm) with a class of theoretical terms T and correspondent rules (CR). So is reflected in the observation language (Lo) (Fajkus, 2005).

According to this approach, the structure of scientific theories consists of abstract formalism F, a set of theoretical postulates (axioms) T and a set of correspondence rules CR. F has two components: a language L, in which a theory itself is formulated, and in which a series of logical inference rules is introduced. L contains mentioned logical and non logical terms. The links between observational and theoretical terms are non logical correspondence rules. The example of correspondence rules is as follows: theoretical mass term is associated with observational predicate "to be heavier than" through correspondence rule of "body mass of Z is greater than the mass of R provided that Zis heavier than R". The interpretation of theoretical terms can only be partial, as theoretical terms are not precisely defined and the number of correspondence rules is not final (scientific knowledge is being developed and the number of CR grows as well). The definition of meaningfulness or significance of theoretical terms opens the possibility for the definition of the advisability of theoretical sentences. This manner of understanding of scientific theory builds on nomological–deductive model of scientific explanation.

Different concept that deals with the problem of a scientific theory is a semantic concept or a model–theoretic approach. The structure of scientific theories is understood here as a set of mathematical models. The basis of these concepts is the term of model. Theories represent the world through mathematical models. In this sense the scientific theory is extra–linguistic — it is a certain structure that can be interpreted differently. Again, the basic problem is the ability of theory as a mathematical model to represent an empirical content. This is possible due to isomorphy of the model with the empirical world, but mathematical models exist only as abstract structures. In this case it is not clear, what are the veracity criteria of this model in relation to observable objects. Therefore, in addition to the concept of model, it is necessary to introduce the concept of the hypothesis, which is the linguistic structure connecting the abstract model with empirical content. The theoretical hypothesis puts a physical system F into the relation with an abstract entity E described by the same model. This opens up the possibility of linking the model and empirical content. The theoretical hypothesis therefore performs a similar function as correspondence rules in the syntactic concept.

3.3 The Criteria of Scientific Theories Validity

E. McMullin describes the difference between the theory and the law from historical perspective on the example of Galileo and Descartes' concept. Galileo did not try to discover the cause of the downward movement. His laws of motion were to some extent a mere description of observed patterns of motion of falling bodies. Descartes tried to explain the cause of this motion by analysis of the composition of the material bodies (he reflected on invisible particles in the material specimens as potential cause). Therefore, the scientific study contains two branches — laws and theories. Laws are more or less idealized descriptions of observed regularities; theories seek to go beyond the observed facts in order to clarify their internal structure (Galileo's concept), to specify the applicable causal laws and provide explanations of observational statements (Descartes' concept). The scientific explanation gradually acquired a nomothetic nature (McMullin, 2008).

Scientific theory is not just a simple interference of law from a set of observational statements. The primary feature of a theory should be the ability to explain the observed empirical data. Yet, it often happens that a theory is partially receding from full empirical adequacy (especially in early stages of its formation). In the process of theory elaboration it is desirable to eliminate all exceptions and abnormalities that are beyond the theory. The process results

in the theory modification (in extreme cases leads to the elimination — cf. Section 3.4). Another characteristic of a scientific theory is its explanatory power. A scientific theory should be internally consistent and coherent with other existing theories; it should eliminate the so–called ad hoc properties and should be characterized by certain simplicity (in terms of Occam's razor). T. Kuhn has proposed three key characteristics of a good theory: accuracy, broad scope and fruitfulness (Kuhn, 1977). According to Kuhn, these six criteria are obligatory for a scientific theory, because they are related to the very nature of scientific research.

For greater clarity McMullin divides the criteria of valid scientific theory into three groups: internal, context and diachronic (McMullin, 2008). Within the internal characteristics, internal consistency, internal coherence and simplicity are particularly important. The context characteristics of theory include the external consistency (i.e.: consistency within the broader theoretical context of other scientific theories and principles of general application — e.g.: the principle of causality).Other contextual feature of a theory is its optimality, which indicates the best known concept of explanation. Diachronic characteristics of a scientific theory are visualized within a longer time period of the validity of a specific theory. These characteristics include fruitfulness, the ability to unify (en. consilience) and persistence (stability).The fruitfulness of a scientific theory refers to its ability to address anomalies and its capacity for effective modifications (cf. e.g.: modifier potential of atom theory –theory employing a model of an unstructured spherical shape through a structured theory of the nucleus and orbital electrons to the current model of the complicated structure of the atomic nucleus).Diachronic features of theory include its ability to unify seemingly unrelated aspects of observed phenomena explained by different laws. A classic example is Maxwell's electromagnetic field theory, which unifies the phenomenon of magnetism, electricity and light. Persistence of theory is related to its ability to generate successful predictions in a broader time frame.

3.4 Problem of Intertheoretic Reduction

One of the central problems in contemporary methodology of science, which is mainly related to the possibilities of development of scientific knowledge, is the problem of identifying the conditions of possibility for intertheoretic reduction (reduction of one theory to another theory). Paul Churchland formulates the problem of intertheoretic reduction as follows: "Intertheoretic reduction is in fact rather a relationship between two different conceptual frameworks that are describing the phenomenon as a relationship between two different aspects of this phenomenon. The purpose of a reduction is ultimately to demonstrate that what we considered as two spheres is in fact one sphere, although described in two (or more) different vocabularies." (Churchland, Churchland 1998, 69). This argument can be illustrated by examples of development of certain scientific theories. One of the earliest is the example of intertheoretic reduction of Kepler's laws of planetary motion to Newton's three laws of motion. Newton's theory in fact proved to be more widespread and systematic and therefore more effective. It explained a wider range of possible movements and was based on a set of clearly defined units, such as force, acceleration, inertia and gravity. "God or the supernatural character of the heavens was lost forever. Sub lunar and lunar sphere were thus united into a single realm, where the same types of objects were managed by the same set of laws." (ibid.). Another model case of intertheoretic reduction is a theory of heat as average molecular energy or identification of sound with pressure waves spreading in atmosphere. All three spheres of movement — lunar, sub lunar and microscopic –were combined into a single theory of motion. The most famous reduction in the history of modern science is the reduction of Newton's laws of motion to Einstein's special theory of relativity.

Based on these cases, it is possible determine the conditions for the possibility of intertheoretic reduction. The reducing theory must be sufficiently systematic, so that predictive or explanatory losses were avoided by the replacement of the old theory with a new one. Reducing theory must therefore include everything that proved to be valid in the reduced theory. This does not mean that the new theory is completely isomorphic to the old, as in many important aspects the reduced theory may be falsified. The old theory can be both reduced, and eliminated, if it turns out to be entirely unfounded. The basic objective of the reduction is to introduce as few as possible explanatory principles, by which it is possible to explain most of the observed phenomena (the principle of Occam's razor).

However, a necessary condition for the application of the unifying approach is, as it has been emphasized, the singular nature of the investigated phenomena, therefore the possibility to explain these phenomena by the same laws, the same language and the same methodology. Today, when identifying a gene with a portion of the DNA molecule, it is a result of applying the reduction between two theories of heredity — the biological and chemical — in practice. "The fact that a property or condition are in the focus of attention of one of our inborn discriminative abilities, does not mean that they are exempt from possible reconceptualization in the conceptual framework of a deeper explanatory theory." (Churchland, Churchland 1998, 69).

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4. Hypothetical–Deductive Inference Method and the Problem of Confirmation of Scientific Hypotheses

Keywords: *theory of inference, scientific hypothesis, observational prediction, initial conditions, qualitative confirmation*

4.1 Introduction

In scientific explanation, there are statements related to observation (direct or indirect) and theoretical statements that arise from the theory of inference. The sources of scientific knowledge are therefore both observational statements and theoretical inference and prediction. The determination of nature of the relationship between these two types of statements is one of the fundamental problems of philosophy and methodology of scientific knowledge. Another relevant issue is how to submit theoretical hypotheses and empirical tests to determine their validity or invalidity.

4.2 Hypothetical–Deductive Method

Hypothetic–deductive method (sometimes called the theory of inference) enables the evaluation of theories based on testing of empirical predictions that are results of deductive theory as its consequences. True predictions confirm a theory and false predictions refute a theory; particularly important is the relationship between theory and prediction

(hypothesis theory), which is also the sole validity criterion of the theory. This relationship has an inductive nature.

Scientific hypothesis (H) is a general or specific statement, from which it is possible to deduce certain empirically observable consequences or certain observational statements. These are formulated as statements whose veracity or falsity can be verified by a series of observations. In addition to the hypothesis, the H–D inference must also include statements that are pointing out the so–called initial conditions, thus the circumstances under which a relevant empirical test (PP) was performed. The conclusion of the HD inference takes the form of observational prediction, which is derived from the hypothesis and initial conditions.

Within the hypothetic–deductive inference, a hypothesis H may have the form of a universal law, for example, for any gas with a constant temperature T, the pressure P is inversely proportional to the volume V (except the cases of such temperatures and pressures, when the gaseous substance passes to liquid state). The H–D inference should be drawn up as follows:

(H) At constant temperature, the gas pressure is inversely proportional to its volume (Boyle's law).

(PP1) The initial gas volume is 1 m3.

(PP2) The initial pressure is 1 atm.

(PP3) The pressure is increased to 2 atm.

<u>(PP4) The temperature does not change.</u>

(K) The volume of gas increases by one half of a cubic meter.

This argument is a valid deductive inference. The subject of the confirmation is a hypothesis of Boyle's law. It is not possible to derive an empirical prediction from a mere hypothesis without specifying the initial conditions. Schematic argument would appear as (Earman, Salmon, 1999):

H (tested hypothesis)
IC (initial conditions)
OP (observational prediction)

In fact, within the H–D arguments we assume other factors, as well — many of the initial conditions and observational predictions cannot be observed directly, but only with the use of aids and appliances. It is necessary to rely on valid measurements of thermometer, or the veracity of the data provided by the microscope or telescope. For example, if a camera is used to obtain data for determination of the initial conditions and verification of observational predictions, within the auxiliary hypotheses it must be assumed that physical theories of optics are valid. All of these assumptions are hidden in the H–D argument called auxiliary hypotheses. A complete H–D inference scheme should therefore be:

H (tested hypothesis)
AH (auxiliary hypothesis)
IC (initial conditions)
OP (observational predictions)

Based on this formulation of inference, it is possible to empirically verify observational prediction. The advantage of the D–N method is the possibility to create a first theoretical explanation hypothesis and subsequently to verify its predictions empirically and to avoid the problematic enumerative inductive method. It provides scientists with a broader application of abstract, directly unobservable entities and models in order to develop new theories.

The problem is that in the deductive argument may appear cases where one or more false premises imply a true conclusion. Therefore, it is not possible to derive an indispensable validity of hypothesis from a proven observational prediction. The H–D inference is a valid deductive argument only in the direction from premises to the conclusion, but not vice versa — that is, from the conclusion to premises. The veracity of the relationship must be proven by induction. If premises were exchanged with conclusion in the above inference, so that all the initial conditions and observational prediction would stand as premises, from which would result a conclusion in the form of Boyle's law hypothesis, it would be obvious that in this case we could not talk about a necessary validity, not even a high probability, of the inference.

Even more complicated situation occurs when an observational prediction is not confirmed in a series of experiments and observations. Which of the argument premises are falsified by it? There even may be a case when a negative test result is caused by additional significant empirical fact that is missing in the argument and therefore an unconfirmed argument does not necessarily indicate an invalid theoretical assumption. W. Salmon describes a case, which occurred when astronomers were verifying the predictions of the orbital motion of the planet Uranus, which were based on the theory of Newtonian mechanics. Scientists have found that their predictions were incorrect. But instead of questioning the validity of Newton's laws, they have postulated the existence of other gravitational forces that affect the path of Uranus. Shortly afterwards, the observation confirmed the existence of a previously unknown planet, Neptune. Another example is the predictions of orbit of Mercury, which also proved to be invalid. In this case, they actually pointed out the invalidity of the theory and measured variations have become one of the principal evidence supporting Einstein's general theory of relativity (Earman, Salmon, 1999).

4.3 Criticism of H–D Method and its Alternatives

One of principal criticisms of the H–D inference method opponents is the so–called Duhem–Quine problem, which points out that it is not possible to deduce an empirical prediction from any theory without adding auxiliary assumptions. If the predictions are not confirmed, the only thing it is possible to derive by deductive means is that either the theory or the auxiliary assumptions are not true. By logical inference it is impossible to deduce, which of the mentioned argument components is the cause of invalid predictions. Therefore, it is always possible to ascribe "fault" to auxiliary hypotheses in order to preserve a theory, as theoretical statements, from which predictions are derived, cannot be tested in isolation from other empirical auxiliary hypotheses. Therefore, according to this criticism, it is never possible to confirm a scientific hypothesis with certainty and thus prove its validity.[1]

The second major reproach to the H–D method is the so–called problem of alternative hypotheses. The essence of the problem is that whenever we come to a true prediction, which confirms the tested hypothesis, at the same time, this true prediction confirms an infinite number of other hypotheses that are comparable with tested hypothesis. If two or more alternative theories generate identical empirical predictions, in the case that these are confirmed, which of the alternative theories do they confirm? In this case, a simpler hypothesis is generally selected (although the connection between simplicity of theory and its confirmatory potential is not clear). The first problem had a more general framework and it did not interfere only with the H–D method. But the second complaint related to the assumption of the H–D inference that the sole condition for the validation of a theory is its predictive power.

The third objection against the H–D method is the so–called problem of statistical hypothesis that applies to cases where observational predictions do not inferentially result from premises. This situation occurs generally in the case of statistical hypotheses. For example, if there is a hypothesis, according to which a certain active ingredient in a medicament causes a shortening of

1) W. Quine has led his criticism to consequences and argued that there is no statement that would be immune to the possibility of rejection, because in contact with empirical reality it is always an experience that determines the modification or elimination of theories. Quine argues that there are no a priori statements (analytic or synthetic). Cf.: Sober, E.: Likelihood, Model Selection, And The Duhem–Quine Problem. In: The Journal of Philosophy. Volume CI, No. 5, May 2004.

recovery after a virus infection, then the hypothesis implies an observational prediction, according to which the recovery time in the experimental group of infected people taking an active substance is shortened. If it is assumed that this prediction is confirmed by a series of observations, what conclusion can be drawn from this observation? The only thing that can be assumed on the basis of the empirical confirmation of hypothesis is a higher probability that the average length of the recovery period in the experimental group shall be shorter compared to the control group. This inference is inductive in nature, since the mentioned conclusion is not deductible from premises (it is not possible deduce a shorter average period of recovery in people who are taking active substance) and, therefore, is not inevitably true.

Within the framework of certain movements in methodology, there are emerging tendencies to modify the H–D method, while emphasis is placed on explanatory function of hypothesis. If it is possible to prove, that tested hypothesis offers the best available explanation of the observed phenomena, such explanatory power can constitute a criterion of its confirmation.

C. Hempel developed the problem of qualitative confirmation and set the criteria of its validity. (Hempel, 1966). He based them on intuitive assumption that the main criterions of true hypotheses are its positive cases. He established three conditions:

1. entailment condition,
2. consequence condition,
3. equivalence condition.

Entailment condition states: if recording of observation E logically implies hypothesis H, then E confirms H. Thus, if the hypothesis assumes the existence of white crows, if there was a report on the observation of white crows, the hypothesis might be considered confirmed. Logical implication is the strongest possible form of evidence. Consequence condition states: if the observation record E confirms each sentence from the set of sentences S, then it confirms any consequence S. Thus, if observations confirm Newton's law of gravity, they should also confirm Kepler's laws (which are its consequences). Equivalence condition states: if H and H` are logically equivalent sentences, then observational report E confirms H if, and only if, E confirms H`. This condition is also derivable from the entailment condition, because if H is confirmed by E and H is equivalent to H`, then H` is the logical consequence of H and the entailment condition is applied.

Condition effect implies two additional conditions:

4. Special consequence condition — if the recording of observation E confirms hypothesis H, then it also confirms each consequence of H;
5. Inverted condition consequence — if the record of observations E confirms hypothesis H, then it also confirms each hypothesis H`, which logically implies H. The stronger a theory is the greater predictive power it has. Thus, if the theory T has the prediction of observational statement E, E is also the prediction of every stronger T`. Confirmed predictions of Keller's laws are also a confirmation of the law of gravity, since they are one of its cases. But if the inverted condition of consequence is recognized, then the case may occur that any hypothesis X is joined to the confirmed hypothesis H and new hypothesis H.X derives its validity from the same evidence E. Under this condition two contradictory hypotheses may be affirmed: if H is confirmed by E, then H.X and H.–X are confirmed by evidence of E (Sprenger, 2012). Therefore eventually Hempel rejected this condition. Contradictory hypotheses cannot be confirmed by the same evidence. On this basis, another condition has been derived — the condition of consistency: if the observational record E confirms hypotheses H and H', then H is logically consistent with H'.

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5. Idealization and Abstraction in Scientific Study

Keywords: *abstraction, abstract entity, idealization, idealization type*

5.1 Introduction

Thought processes, which are called idealization and abstraction, are widely used practices in all disciplines. They are applied in the formulation of natural laws and theories and in their practical applications.

While formulating the first law (law of inertia), Newton thought of an ideal object, which is unaffected by any external forces. Similarly, in the case of laws concerning the reactions of gaseous substances, scientists are considering an ideal gas. The idealization of very complex and large–scale phenomena in science has proven to be a good strategy when it is not important to consider all the properties, effective causes or circumstances of the phenomenon, but only the facts that are relevant to the understanding of the phenomenon, are selected. Thus, for example, physics is considering a massive scale bodies (e.g.: planets) as a symmetrical round shaped objects, or ideal crystals that have no additives or deformation.

5.2 Abstraction and Abstract Entities

The introduction of language and communication code in it is a subject to a degree of idealization and abstraction. J. S. Mill describes this thought process as follows: "The mind can imagine a huge number of individual things as a single file or a class and general terms evoke certain ideas or mental representations, otherwise we could not use the names of things and realize the importance of doing so. And this general idea represents in our minds an entire class of things, to which the name refers. Whenever we think of class, we use this idea. And the ability of mind to focus at any time and observe one part of what is present in it, allows us to keep our thinking and reasoning within classes, untouched by anything that it is not real in the idea or mental image, but only common to the whole class."(Mill, 1950, p. 213). The abstract term is the result of abstractive cognitive operations; it is separated from specific sensory perception and contemplated only on its own. For example, the term "quality" creates an abstraction of various qualities of different types of objects. If the environment and objects, from which the concept of "quality" is abstracted, never change, it would be impossible to know how to attain this abstract concept. Similarly, says W. James, if all wet things were cool at the same time and all cool things were wet at the same time, a person could never understand and abstract qualities of "humidity" and "coolness" (Jones, 1909). Paradoxically, it is the existence of various qualities that allows one to create the abstract entity of "quality" and understand its meaning.

The outcome of an abstraction process is therefore an abstract entity, which is a sort of separate object for human mind. For example, in case of the quality of "colour" by disregarding the other qualities of the observed object the colour is perceived as a separate object. Thus, in the process of idealization and abstraction a specific type of abstract entities is being formulated. They are created by certain types of object qualities that are excluded from their "natural environment" and thus modified they act as separate entities. An abstract term may be a relation name (quantitative or qualitative), interactions, activities, etc. The relationship between abstract and concrete, as already mentioned above, is not clearly defined. For example, "red" is an abstract concept in relation to a red object, but a specific term in relation to the concept of "colour". Abstract concept can be used in specific and general sense. For example, the term "government" is used in a general sense to define democracy as "rule of the majority", but also in the specific meaning of "present government is democratic." In logic, the error that occurs due to the incorrect use of abstract term (in a general sense, when a specific situation is being discussed and vice versa), is called fallacy of accident (Jones, 1909, p. 56). For example, if a person comes to a conclusion that black men are small on the basis that he/she saw one black man who was small, one commits an opposite logical error — formulating an abstract concept from a specific event. Similar erroneous train of thought may be illustrated by an example from the ancient world: "The Greeks create masterpieces." "Spartans are Greeks." "Spartans create masterpieces." Term "Greeks" is used in both premises, but in different sense (in the first premise it used in general sense, in the second premise, it is used in specific sense). Similar mistakes may be committed, if one considers the right to freely sell poison, because it is very useful in medicine.

Abstract entities are therefore entities that exist outside of time and space and are immutable as e.g.: numbers, propositions and sets. They exist in relation to particular specific entities, but they are not necessarily contradictory. For example, Aristotle understood number as a universal entity that exists only in particular entities existing in space and time. G. Frege describes in the example the abstract notion of "direction" (D) how abstract entities may be introduced to a theory: the direction D of the straight line U is the same as the direction D of the straight line V if, and only if, U is a straight line parallel to straight line V. The term direction is

not directly and intuitively understandable; it is an abstract entity, which can be reached by a certain deliberate consideration. This Frege's introduction permits the identification of an abstract object ("direction") as the very same within other descriptions as well.

5.3 Idealization

Scientists generally do not challenge phenomena or events as particulars, but as phenomena that are organized according to certain rules and patterns and are interpreted by certain theories. Therefore, the idealization of subjects is essential if complex systems are to be captured in the form of theoretical descriptions. Sometimes, it even happens that theoretical definitions contradict the description of phenomena, which they explain. Examples include Kepler's laws of planetary motion, which describe the kinetic properties of the planets in the heliocentric system, and this model is "tailor–made" for extensive measurements collected by T. Brahe (Ladyman, 2008). Accurate elliptical paths described by Kepler are actually unrealistic by taking into account the gravitational interactions between the planets and the sun and the planets themselves. Therefore, P. Duhem understood physical concepts as abstract and symbolic formulas, which describe only imaginary constructs. For example, physics utilizes mathematical idealization of the continuum of real numbers where physical quantities are understood as real numbers. For the continuum of real numbers, however, applies that any determined interval between the elements of this continuum shall have as many elements as another final interval within this mathematical model, while their extension may vary. To be able to apply mathematical idealizations of the continuum of real numbers in physical theories, space–time must therefore be understood as continuum, which may be a source of inaccuracies, because the structure of space–time is in fact discrete. For example, a body that is in relation to the Earth's surface in a state of rest is described as inert (while it is well–known that the Earth, and everything that lies on it, in fact rotates). This idealization is possible only if the dimensions of the body are considered negligible compared to the diameter of Earth, so from the perspective of the body the Earth's surface appears to be perfectly flat.

Another example of the application of idealization in science is the fact that physical structures are intended to be subject to precise symmetry. The symmetry in physics means invariance, stability in changing conditions and transformations. For example, a cylinder remains invariant during the rotation around its axis. A sphere has an even greater degree of symmetry, therefore, remains invariant during rotation around any central axis either. Similarly, the laws of science are characterized by symmetry; they apply in different reference frames. The example would be Einstein's principle of relativity, which states that the laws of physics must be the same for any two observers moving at a constant speed relative to each other. Several types of symmetries may be distinguished: global and local, linear (continuous) and discrete (discontinuous), geometric and internal (Morrison, 2008). The global symmetries are symmetries, which are not affected by the position in space and time. In the case of local internal symmetries, the rotations of field particles vary from place to place, so for different positions in space symmetries may not be mutually compatible. The example of a discrete symmetry is the rotation of a triangle or a square or symmetric reflection in the mirror.

Idealization aims to simplify and adapt the examined phenomena sufficiently, while they still keep their empirical potential. However, it is difficult to establish criteria that would separate legitimate idealizations from unrealistic fiction. McMullin considered Galileo to be the founder of the scientific method of idealization and claims that two methods of idealization can be found in his intents: either the conceptual representation of the object is simplified or a given problem situation is directly idealized. The first method is called *construct idealization* and a good example of this type of simplification is the description of a hanging object

forming a right angle with the anchor point. Construct idealization is used generally in the scientific models development and within it McMullin distinguishes between formal and material idealization. The formal model is applied in the construction of mathematical models by simplifying certain factors, often relevant to a given situation (the Sun is viewed as a stationary object when calculating the orbits of planets, even though its movement ultimately reflects on orbit of these planets). Material type of idealization is one, in which all irrelevant factors are eliminated (for example, material composition of the Sun, which is irrelevant to its gravitational effect on the Solar System). The second method is called *causal idealization* (McMullin, 1983). In this case, a causal effect, mutual causal interactions, which are mostly a tangle of other powerful causes, is being simplified. This simplification can be carried out under experimental conditions, while deliberately eliminating the effect of certain causal forces (it is an experimental causal idealization). A simplified model of causal forces impact can be constructed in a thought experiment or when considering hypothetical possibilities.

N. Cartwright specifies the difference between idealization and abstraction (Cartwright, 1983). She understands idealization as a simplification that is capable of manipulating (theoretically or experimentally) specific objects or real situations in order to select important qualities and functions and provide their explanation. Abstraction is a higher degree of idealization, because the physical properties of objects (for example, their composition) are eliminated as a part of that, or certain types of causal interaction are disregarded. Therefore, in case of abstraction, more or less unreal and fictitious objects are being considered. This type of object is important for the possibility to postulate universal laws of nature. Some authors understand the idealization rather as the prediction of certain properties of objects than as a reference to fictional objects (within the meaning of Plato's idealism). When talking about an electron as a physical point, the idealization is intended to establish the relevant characteristics of an electron, which does not include its spatial dimension. However, such characteristics as quantity, spin, charge, and others, remain relevant in relation to the term of an electron.

The use of idealizations in the development of scientific models is becoming more and more important. Idealizations and models based on them are understood to be the very core of scientific knowledge and theories serve as tools for their formulation.

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6. Models and Analogies

Keywords: *model, representation, model types, analogy, metaphor*

6.1 Introduction

> Theoretical model is a structured set of theoretical premises about the target object X which represents the basis for the object X exploration. The selection of theoretical premises is defined by basic similarities (analogies) of the target object X and other known object Y.

The scientific model has mostly the form of quantitative mathematical model. The main function of the model is to represent the known object. Many questions can occur in connection with this function: How are the models created and what are their constitutional elements? How can the model be related to the reality and represent it? To what extend can the idealization influence its representation function? In what sense, is the model a new source of knowledge?

6.2 Models and Their Types

Scientific model cannot be viewed as a precise replica of its object but as an idealized and abstract representation. The model selectively mirrors only several features of the presented object. For instance, architectonic model of a building presents only spatial arrangements, while it does not cover the objects infrastructure. The main characteristic of different model types is their representing function which is defined by the cognitive processes of idealization and abstraction (see Section 4).

The representing function of a model is a result of its three partial functions (Kühne, 2005):

— Function of mapping which mediates the relation between the model and the original
— Reductive function based on which the model reflects only relevant characteristics of the model
— Pragmatic function which provides efficiency of the model in practice

A model cannot be a simple copy of the object because in that case it would resign on its reductive function. Similarly, it is not only a description because it is defined with regard to its specific purpose. E.g. if we created a model of a very complex system, which would be equally complex, it would lack the purpose. Model of a complex system must be primarily its simplification.

The psychologist K. Craik introduced the term of a mental model. He understood it as a psychological representation of real or hypothetical situations, which has a form of a reduced scale of reality and aim of which is to support and stimulate cognitive processes applying to phenomena explanation (Craik, 1943). Mental model is formed in working memory as a result of the process of perception, thinking and imagining. An important factor is mostly its structure which should correspond with the structure of the object which it represents. P. Johnson–Laird postulates the difference between mental model and other mental representation, which has the form of a propositional representation. The statement: „Triangle is on the right from the circle." is in case of propositional representation attention concentrated on the syntactic structure of this predication (at the position of predicate, subject and object).

Propositional representation has syntactic structure and it is the basis of the language of thought. On the contrary, the mental model represents the spatial structure which is isomorphic with actual spatial disposition between two objects. The model „excerpts" from the reality, which is common in all cases, where the triangle is on the right from the circle. The size of objects, their mutual distance and position can secondarily supplement each other, which specifies the model (Johnson–Laird, 1999). Formation of a model on the basis of propositional representations is a part of the cognitive process of understanding. Based on this process, analogies can be created and connections can be revealed. Mental model as a result of the perception and analogies searching represents the base for higher cognitive activities (e.g. for argumentation). Formation of models from models themselves is the basis of metarepresentation which is a critical condition for existence of the consciousness.

There are several model types used within scientific research:

— Iconic or scale models — represent objects as idealized and abstract structures (for example, model of a DNA molecule)
— Analogical models — represent objects on the basis of analogy which is based on the relation of similarity between the model features and features of its object
— Mathematical or abstract models — represent its target objects by means of formal language of mathematics.
— The differences between various model types lie in a different way of implementation of the representation function (Portides, 2008).

6.3 Analogies

The Greek origin of the term analogy indicates its primary meaning — proportion. Proportionality is related to, for example, numeral relations — relation of 2 to 4 is proportional to the relation between 4 and 8. Analogy points out the similarity of relations within various domains. The basic scheme is: A is related B as C is related to D.

Two situations are analogical when they have common pattern of relations between their constituents, also despite the fact that the constitutive elements differ in individual situations. For example, electrons are related to atomic nucleus as planets are related to the Sun. Ch. Darwin used analogy when comparing process of plants cultivation in agriculture and process of natural selection. Analogical thinking uses the existence of proportional relations between starting and target system and on this basis derives probable new features of target system. Therefore, analogy is a form of inductive reasoning. It is based on asymmetry between the original knowledge and new knowledge. It can originate from formal or material similarity. Formal analogy reflects the structural proportionality, while it does not require (unlike the material one) the identity or similarity of the attributes of the compared elements. An example of formal analogy can be the orbital movement of electrons and planets source of which are the gravitation forces. However, the nature of these forces is different (in case of electrons it is electro–magnetic force, in case of planets it is gravitation). Therefore, in this case we are talking about similarity of phenomena, not identity (material analogy). M. Hesse distinguishes three kinds of material analogies: positive analogies (identify common features of two different systems), negative analogies (identify features that distinguish one system from another)and neutral analogies (identify features that are yet not possible to be considered as positive or negative analogies, they are just assumed to represent one of these cases). An example of neutral analogy is the premise: Y can play heuristic role at revealing further characteristics of X (Hesse, 1967).

Analogy has a wide range of application within model formation because it helps their explanation function. Explanation is in certain context transition from something unknown to something known. Analogies enable to specify the new knowledge by its comparison to something that is already known. In scientific research analogies are applied also when new terms are introduced, when

the similarities with the already exiting terms are pointed out, the relations between the "old" and new terms are created and in that way their position in valid system is indicated. This way the analogical thinking can lead to new laws formation and theories modification — if the similarities between two phenomena are identified (for example electro–magnetic and gravitation forces), while laws that determine one of them are known, then it can be assumed that analogical laws will apply also for the other phenomenon, while the degree of validity probability of the assumption depends on the degree of parity of the compared phenomena. The similarity can be manifested as relations similarity (e.g. interference in waves on water and light waves) and as a similarity of objective characteristics (e.g. oxygen as well as helium appears in gas state at room temperature) (Bailer–Jonesin, 2002). The principle of analogy is applied also for the models themselves. This process can result into formation of wider and more abstract schemes cases of which are the individual models. For example Darwin's use of analogy while formation of the concept of natural selection led to creation of even wider generalisation — theory of selection that found application also in the field of economic sciences, genetics or artificial intelligence (Holyoak, 2005).

A model can be based on analogy but it is not completely defined by it. When evaluating a model, the criterion is not the degree of its parity to the represented object but the fact whether the model enables somehow grasp the examined object and thus interpret the collected empiric data. The relation between a model and analogy is that analogy helps the model formation. However, the goal of the model is to create analogical reality to the empiric data.

6.4 Models and Metaphors

A model is a certain interpretation of empiric phenomena and as such it is their partial description. The purpose of a model is not to cover all aspects of examined phenomena as it is with metaphor (although a metaphor does not necessarily have to be an interpretation). The main function of a metaphor is to bring the term meaning from "familiar" area of application into target area. Some scientific models can be analysed in relation to their metaphorical function because they include the notions transfer from the known into the unknown area (e.g. in case of artificial neuron networks). Metaphorical model proves itself very efficient, mostly when forming new theories and introducing new entities, where no used terminology, which could be used (e.g. in case of quantum mechanics theory, black holes theory, etc.), is available. Metaphoric terms are applied in case two correlating areas are viewed as certain structural analogies. For example, a significant progress in explanation of human cognitive capacities within the cognitive–scientific research was achieved by accepting the so–called computer metaphor. Human brain and human mind are explained on the basis of the similarity of the relation between hardware and software which works in computing mechanisms. Introduction of this metaphor enables the omission of long–term discussed problem of two mutually independent substances — physical and mental.

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7. Reductive Method

Keywords: *reduction, science unity, unification, elimination, reduction types*

7.1 Introduction

The basis of reductive method can be found in mechanical science of the seventeenth century which determined one of the key conditions of scientific explanation. Objects which are observed in natural world must be explained on the level of particles that they consist of. Explanation covers the particles behaviour and relations between them. Such understanding of scientific explanation is called reductionism.

Reductive explanations originate from the assumption of natural hierarchical arrangement of observed phenomena which reflects on the organisation of scientific recognition. Therefore, there is a distinguished number of sciences which are similarly organized hierarchically — from psychological and social sciences up to physics of elementary particles. Each of these "levels" of scientific explanation has its own dictionary, set of explanation principles and research methods, which together form an independent ontology of the specific area. Some scientists are thinking of the possibility to create a so–called theory of everything, which would explain maximum of observed phenomena with minimum of explanation principles (fundamental laws). In the fourteenth century, W. Ockham formed the principle of reductive explanation, which is known as „Ockham's razor". According to this principle of explanation economy, subsistence should not be multiplied unless it is necessary (entia non sunt multiplicanda sine necessitate).

7.2 Unification Process and the Problem of Science Unity

Many scientists see the basic science tendency as a road towards creation of a single theoretical system, which would systematize all available knowledge.[2] This tendency should result in creation of integrated (unified) science. However, the unification process itself is problematic. The opinions on how to reach the unification differ. Basically, there are two types of unification distinguished: (1) type based on and similarity (type unification, TU); (2) based on functional interconnection and coordination (conjunctive unification, CU) (Jones, 2004). In the first case, unification is based on manifesting common characteristics, similarities. In the second case, unification is understood as proving the connections and functional conditioning between different entities.

There are various degrees of similarity and degrees of interconnection. A weak type of conjunctive unification is integration of a group of objects, which are connected by spatial arrangement (e.g. when creating villages, cities, regions, states etc. when creating geographic locations) or time concurrence (e.g. when formulating historic periods). A strong type of CU is explanation of various events as causally conditioned or organized into wider integrated functional systems. Between these two marginal CU types, there is a number of interstages, where relations and functional conditioning gradually appear among diversified phenomena, which were considered as reciprocally unrelated. In case of type unifications it is about proving that the different–looking entities or features

2) Unifying tendencies were supported especially by C. Hempel and his theory of deductive–nomological explanation (Hempel, 1965) and E. Nagel and his model of reductive explanation (Nagel, 1961).

can be merged under one general type. The strongest TU type is the reductive identification where the examined phenomenon is explained on the basis of identification with other phenomenon within explanatory stronger theory, by which it is eliminated. An example is the Maxwell theory of electromagnetism which explains the light so that it identifies it with electromagnetic radiation (see section 6.4). On the contrary, a weak TU type is proving that different objects are part of wider category of objects, which have some common characteristics. Even weaker form of unification, based on type similarity, is proving that objects are members of a wider group. However, not on the basis of set of similar features, but because based on some similarity every member of the group is related to the central prototype (an example is fish species, in which there are individual families integrated based on the minimal number of signs shared with the prototype. Type unification can be defined on the basis of internal or external similarities. For example, members of the „vertebrate" group are merged into one group based on their common internal characteristic (they have spine. On the contrary, members of the group „gene" are unified based on the common external characteristic, which is causing specific effects within developing organisms while the similarities in internal structure are only secondary (Jones, 2008). Functional features, based on which the objects are integrated into a group, can be implemented in various ways, within various internal organizations.

Another form of natural phenomena unification is the theory merging, based on a characteristic which they lack, while they differ in other characteristics. For example, identification of various types of mental illnesses is based on this way of classification (e.g. an illness called „prosopagnosia" is characterized by the inability of the subjects, suffering from this illness, to recognize their own face). In case of inter–theoretical reductions, which are very effective within scientific explanation, type and conjunctive unifications are applied. On the basis of functional cooperation it is possible to include various phenomena into unified explanation framework (CU) but this process often presumes identification of similarities between phenomena on a lower level (TU).

Besides unification, which applies to subjects of examination, also unifications on the level of examination methods (e.g. epistemologic unification) and on the level of the scientific explanation form and aim (so–called normative unification) can be selected.

The problem of unification of scientific explanation is a highly complicated and a complex problem but at the same time on the grounds of a limited number of explanation principles, it is possible to describe the behaviour of a wide range of observed phenomena by one of the sources of intense progress and effectiveness of scientific recognition.

7.3 Reduction and Elimination

> Reductive explanation is basically based on determination of certain type of relation between entities. In connection to reductive explanation there can be two basic problems described while defining this relation: (1) between what types of entities a reductive relation can be indicated, (2) what is the nature of the reductive relation.

Reductive explanation can concern events, phenomena, characteristics, objects (ontological reduction), or theories, terms, models, schemes (epistemological reduction). Besides this classification, also various degrees of scientific reduction can be distinguished: (1) reduction within one level (including the inter–theoretical one–level reductions), (2) abstract inter–level reductions (explanation of higher–level characteristics on the grounds of lower–level characteristics), (3) spatial inter–level or strong reductions (scientific

explanation focuses on description of the elementary physical particles behaviour) (Sarkar, 1998).

One–level reductions do not originate from postulating of hierarchic organization of the examined object. The most frequent are the so–called successive or consecutive reductions when the "old" scientific theory is replaced by the "new" theory while both theories cover the same level of explanation. Determining are the relations between theoretical structures while reductions rather take form of derivations (including approximations) than form of deductive arguments. They are mostly applied within mathematical models.

Inter–level reductions are conditioned by abstract levels postulating of examined phenomenon organizational structure. With this type of reduction, it is not about the relation between theories, (it is not about searching the similarities or differences between theories). They rather take the form of bridge laws because objects, characteristics, relations are explained by specified quantitatively different mechanisms of lower level. Such explanations have composition character because there are explanations on lower and higher level which are related to the same phenomenon. Inter–level reduction does not mean elimination of individual levels. Terms, entities or relations from the higher level do not "disappear" within terms, entities and relations of the lower level, they only transform, expand or contract or change in a different way.

The spatial inter–level reductions are composite while explaining principles are formed on the level of physical area. An example is the theory of gene, which based on inter–level reduction transformed into the DNA theory, or the theory of heat which transformed into theory of medium kinetic energy.

A classic theory of inter–theoretical reductions is the T. Nagel's concept. Nagel's model of reductive explanation is a version of deductive–nomological explanations. Explanandum in this case is the law that should be reduced. It is a relation between two laws. Successful inter–theoretical reduction is conditioned by the following two principles: the condition of deducibility — laws of one theory must be able to be derived from the laws of the other theory, and the condition of connectability — terms in two theories must be connected by bridging laws (Nagel, 1961). Nagel's theory of inter–theoretical reduction is formed as an epistemological and not an ontological concept. J. Searle in relation to this describes several types of reduction: a) ontological reduction — it is a strong type of reduction (e.g. in case of water definition as a H2O molecule), b) ontological reduction of characteristics — specific characteristic of an object is explained within the characteristics of lower level (e.g. when a characteristic "have certain temperature" is defined as a characteristic "have specific average kinetic energy"), c) theoretical reduction — is one–level reduction among various scientific theories (e.g. including Newton's movement laws under general theory of relativity), d) definition reduction — covers the possibility of reducing the definitions consisting of words and sentences, which refer to the same object, e) causal reduction — causal influences of reducing entity have bigger explanation power than causal influence of reduced entity (Searle, 2000).

P. Oppenheim and H. Putnam created a concept of reducing all objects to physical objects — elementary particles — which is based on strictly hierarchical arrangement of surrounding reality (from elementary particles through atoms, molecules, cells, multi–cell organisms, etc.). Basic level (n) of elementary parts consists of certain number of constituting elements, while the closest higher degree of reality (n+1) is created by structuring of elements from the level (n) (Oppenheim, 1958).

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8. Observation

Keywords: *scientific fact, empiric criterion, observer, quantum phenomena, asymmetry*

8.1 Introduction

Scientific observation in research practice is characterized by such attributes as systematicness, activity, planning, controllability, etc. Basically, the scientific observation can be divided into categorized and non–categorized, which are further divided according to the degree of involvement of the observer.

Categorized or controlled observation is structured according to certain standards and systematizing tools (schemes, standards, questionnaires, procedures, etc.). Direct systematic observation is an observation during which the observer is present as its part unlike the indirect observation, which uses the data collected by someone else (documents, archived materials, laboratory protocols, logs, etc.). When assessing the reliability of the observation, criteria such as type of contact with observed phenomenon, degree of observation structurizing, time and length of executed observation, its frequency are used. Also the conditions, under which the observation was executed, are assessed (Juszczyk, 2003).

8.2 Problem of Facts

Some science theoreticians denote the new attitude towards observation as the key factor of the new modern science — observed empiric facts are respected and they are becoming the basis of scientific examination. This “transition” occurred at the beginning of the seventeenth century when facts were understood intuitively as a) directly accessible to attentive, not involved observer by the senses medium, b) preceding any theory, c) constituting strong and reliable basis for scientific knowledge (Chalmers, 1999). Nobody questioned the existence of directly accessible data about the world which are mediated to us by the senses and which are the same for different observers performing the observation from the same place. Thanks to this, science in this period represented an area of relatively stable agreement in basic characteristics of empiric reality. The difference between everyday perception and scientific empiric experience was given only by more detailed and accurate perception (or by using some tools designed for expanding the possibilities of direct observation). Observed objects constituted indubitable data within the experience, in which the true essence was revealed. The data were “dictated” by the nature itself, therefore their status was objective. During the period of prevailing theory of logical positivism (the 1920s and 1930s) what was observable, became the criterion for meaningfulness of scientific predications. Scientific language was an observation language, terms of which related only to directly observable objects’ characteristics (Ayer, 1936). In case of psychology, a scientific statement would not apply to mental states but to behavioural expressions. This form of scientific description did not take root because certain degree of abstraction and idealization was necessary within the scientific conceptualization of the world. Therefore, theoretical terms, which were not related to the observed phenomena, were used within the deductive–nomological model and hypothetical–deductive model of scientific theories confirmation. However, there was a requirement raised towards scientific theory; to make it possible to derive observation statements, which would be subject to empiric testing. Confirmed observation statement, which was deduced from a hypothesis, became the standard of this hypothesis veracity (or scientific theory) and represented a criterion based on which it was possible to evaluate rival theories.

During further development of scientific methodology, the empiric criterion of fact or data appeared to be quite problematic (Démuth, 2013). The problem of identification of observed fact can be exemplified on the case of theories of consciousness. Human consciousness is a fact, existence of which no one denies. However, if we think more closely about the question which empiric fact we are observing when we observe human consciousness we discover that it is a complicated problem. Here, we are dealing with observation of two kinds: depending on subjective or objective perspective, we observe either physiological processes or personal experience. „So, what leads us to considering two sets of observations to be observation of the same event?" (Place, 1956, p. 70).

In order to be able to consider the consciousness and brain processes identical, we have to rule out the possibility, that there is a causal relation between them, like between two independent entities. For example, as in the case of photosynthesis, we observe the causal effect of light on a plant. The plant has evolved so that the light energy could invoke the photosynthesis process in it. However, based on this, it would be incorrect to imply that light and photosynthesis are identical. It is clear that these are two separate phenomena connected on the basis of the cause–and–effect principle. How do we exclude the possibility that a common relation exists also between brain and consciousness? So what is the subject of observation when we observe the consciousness?

Another problem is the process of observation itself. It does not represent passive approach towards the surrounding course of events, without any manipulation with it (Démuth, 2013). Today the data set of everyday perception and scientific observation

form almost incompatible sets. Currently, also the status of the observed things itself is becoming problematic — what is and what is not observable? In scientific observation the attention is paid to objects with size of 10^{-30} m and to time periods 10^{-40} s. These parameters and durations are not only directly unobservable, but the events occurring in microcosmos are often contra–intuitive in respect to our everyday experience.

8.3 Problem of Observation in the Theory of Quantum Physics

Within the quantum theory of fields, which connects quantum mechanics, Maxwell's electro–dynamics and Einstein's special theory of relativity, the status of observation proves to be even more problematic than in the case of the macrocosmos objects. We encounter some phenomena, which are in direct contradiction with our everyday experience. In a well–known experiment with individually emitted photons, which transfer through two open holes and fall on monitored shade, a paradox fact can be observed. There are spots on the shade, on which none of the photons falls, although in the case when only one hole is open, photons fall on these spots. If we take into consideration the fact that only one photon is emitted, this phenomenon can be explained by the statement that photons "disturb" one another, but only the possibilities of transit through one of two open holes can collide. During this experiment, the photon is in the state of two overlapping possibilities of transit (through upper or lower hole), which is called superposition. The significance, with which both states contribute to the resulting state, is expressed by a complex number. Complex number may be presented with the so–called Gauss's plane, where the x–axis represents the irrational number and y–axis is multiplied by the second radix of minus one. The complex number will appear in this plane as a point. Complex numbers enable to determine the significance of individual states of elementary particles and they differ from irrational numbers which would determine only the probability with which one of the potential states will occur. In case of expression by complex number, also the reciprocal cancellation of two potential states can be expressed. The state of the photon can be mathematically expressed as: w x (alternative A) + z x (alternative B), where w and z are complex numbers (Penrose, 1999). On the quantum level the system state is expressed as a ratio of potential states, significance of which is expressed by complex number as superposition of all potential alternatives. The development of quantum state in time is described in the so–called unitary evolution, which follows the Schrodinger's equations. „Superposition of two states is developed as a superposition of states developing individually while complex significance of both states in the resulting state are constant in time." (Penrose, 1999). Thus individual developing states contribute to the final state always in the same way. However, the problem arises when the events, occurring on the level of quanta, want to be explicated in terms of standard Newtonian physics which applies to macrocosmos level. Within this transition a change of rules occurs, which brings indeterminism into the theory. Linear superposition (systematic coexistence of individually developing states, which have the same significance) disappears and it is replaced by the probability of one of the potential states. Because we want to measure the quantum phenomena, we interfere in unacceptable way into the observation process and the observed phenomenon is deformed. Within the quantum level there are valid laws (Schrodinger equations) and strict determinism. The same applies to macro level where Newton's movement laws, Maxwell's equations of electro–magnetic field and Einstein's theories of relativity (general theory is valid in strong gravitation fields and special theory applies at high speeds) are valid and objects are strictly deterministically organized. However, during the transition from one level to another which occurs e.g. during measurement of elementary particles behaviour, the so–called collapse of wave function occurs and the quantum theory becomes indeterministic. Also other phenomena are observed in the quantum field

which have no analogy in the standard physics — e.g. quantum cohesion phenomenon (two individual objects on the quantum level are not completely independent, nor interconnected. However, they are somehow linked).[3]

8.4 Relation between Theory and Observation, and the Problem of Incommensurablity

In respect to the possibilities of scientific observation, also the relation between observation and theory becomes more problematic. French mathematician, P. Duhem questioned the possibility of independent observation and stated that scientific observation is not only reporting on object data but also the interpretation of this phenomenon which is set into certain theoretical scope and to which also our (often unconscious) opinions intervene. The observed phenomenon is described in theoretical language working with abstractions, idealizations, symbols, models, etc. Therefore, in various theoretical concepts using various conceptual and terminological systems for the observed object description, it cannot be referred to the same object.

T. Kuhn led this finding to implications and claimed that scientists following different theories see different things. However, in that case there would not be any possibility for objective, theory–independent observation, which would be the criterion for scientific hypothesis validity confirmation and there would be no proof based on which one theory could be preferred to another. There would be no clear data, which represent the empiric base of every science. Scientific theories would become incommensurable (Kuhn, 1962) and there would be no way of presenting the description of

3) Some authors propose to move from the so–called classically — definitive idea of objects and their states (where only one of logically possible states corresponds to every object) to such ideas which would help us comprehend and interpret substance of quantum mechanics descriptions via alternative terms compatible with quantum mechanics (see: Gomatam, 1999).

the observed phenomenon so that the meaning of concepts and terms of language used for description would not be significantly connected to a specific theory. Similarly, P. Churchland argues: „When a child begins to use the word „white" as a response to a known type of perception, it does not set any semantic identity to this term. That is acquired when and only when it includes this term into the network of imaginations and correlative images and inferences. It depends on what network it creates, whether the term "white" will mean white and not hot or unlimited number of other things." (Churchland 1979, p. 14). According to Churchland, experience determines what we perceive, e.g. a „trained ear" of a musician recognizes structure, development, different variations, etc. in a song, which an untrained listener does not catch (Churchland, 1988) at all. Opposite philosophical trends, which defend the possibility of independent observation (theory–neutral observation), object that if this viewpoint was accepted, any statement could become an observation sentence depending on the theoretical context, perhaps even — in material sense — anything could be observable depending on theoretical context. J. Fodor objects that not all our opinions influence our perception. As an example he presents persistence of optical illusions (specifically Muller–Lyer's illusion), to which we succumb also when we have the knowledge about its illusive nature (in case of the mentioned illusion, one of the vectors seems shorter than the other, although we know their length is the same). According to Fodor, this very case proves the very opposite to Churland's predications about the impossibility of independent observation — the way, how we perceive the world, does not change by what we know about it (Fodor, 1993).

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9. Scientific Prediction

Keywords: *prediction, causality, types of causality, probability, probabilistic predictions*

9.1 Introduction

Prediction within scientific context is understood as an implication of theory, or as what results from the theory based on empiric reality regardless of the current state of empiric knowledge.

For example, cosmologic model of early space (according to G. Gamow — author of the idea about the space time origin, later named The Big Bang Theory) assumed that until today there should be radiation which is the remains from the early development period. Relic radiation was really discovered in 1964–1965 which was an ultimate confirmation of the validity of Gawon's assumption and general acceptance of the theory of expanding space. Thermal nature of this radiation precisely corresponds with the theoretical predictions and laws (specifically Planck's radiation law) (Grygar, 1997).

The significant factor in scientific predictions is not the time factor but the epistemic one.

As it results from the above–mentioned example, it is important that the prediction covers realities which have not yet been explained and not those which have not yet happened.

Thus scientific prediction is some "diction" of theory from which it was derived and it can deal with past, present and also future phenomena.

Therefore, it is "timeless" in certain point of view. K. R. Popper understood existence of risky predictions about unexplained phenomena, which can potentially falsify a theory, as an indicator of scientific theory authenticity, which differentiates such theory from various pseudoscientific theories. Scientific theory predictions are one of the key factors of its confirmation or disproval possibilities.

9.2 Prediction and Causality Problem

D. Hume postulated the well–known question, which in connection with scientific prediction appears as the key one: How can we come to cognition, which is not mediated through empiric experience or the memories of it which are stored in our memory? (Hume, 1975). This question deals with the possibility to form statements, in which the present experience extrapolates into the future, or it is used to explain the past. How can we be sure that causal relations, which are valid today, were valid also in the past and will be valid also in the future? Hume points out to the fact that in prediction of change (past or future) of the causal relation there is no logical contradiction. On the contrary, in everyday life we see many examples when future cannot be predicted based on the present or past events. That is, every prediction presumes causal structure of the world and to that connected determinism. In case of causality, the key question is the relation between the cause and effect — based on what we assume that certain event is the cause of another event? The philosophy science distinguishes two ways of understanding the causal relation — relation between the cause and effect has either the nature of dependence, or it is a relation between production, effect and the cause. In the first case, causality is the significant relation between discreet events. If A causes B, then B depends on A. There are several types of thus understood causal relation. It can be nomological causal dependence (relation of cause and effect has a character of law), relation of hypothetical dependence (if the cause did not exist, the effect would not exist either) or the relation of probable dependence (the cause increases the probability of the existence of the effect). In case of the relation of production C is the cause of D, it means that something from effective cause creates (produces) certain effect, so certain "mechanism" connects the cause with the effect. The causality is characterized as the process of transfer from the cause to the effects. The cause and effect must be somehow locally connected (as it is e.g. during force, heat, el. charge, etc. exchange).

The concept of nomological dependence comes from Hume who explained causality as a constant conjunction, regularity or succession between two different events, which are space–time adjacent. However, that implies that there is no necessary connection between causes and effects. Causal relations are denoted as laws of nature, which emphasizes their regularity but also the empiric and indicative character. Using the deductive thinking process never leads to defining the causal relations. According to Hume, only thinking about the specific cause idea, we cannot predict to what effect it will lead. If e.g. we have only visual experience of sugar, we cannot predict whether it causes sweet taste to the gustatory receptors (ibid.). Within this concept, there can be causality without regularity (so–called singular causality) and also regularity without causality — cases, which regularly follow one another and are not connected in terms of cause and effect (e.g. day and night).

The concept of hypothetical dependence originates from postulating the causal chain hypothetically dependent events, where events A, B, C are hypothetically dependent when B hypothetically depends on A, C hypothetically depends on B, etc. Causality is a transitive relation: if A causes B and B causes C, then A causes C. Thus certain event is cause of another event when it is possible to create causal chain which leads from one event to another.

In the probabilistic causality concept the causes are what increases probability of effects occurrence — probability, that certain event will occur is higher if its cause is considered. Then A causes B, if (1) the probability of B occurrence is higher in respect to A than the probability of B occurrence in respect to non–A, (2) there is not any other factor A1 so that, the probability of B occurrence in respect to A and A1 is still the same as the probability of B occurrence in respect to A and non–A1. Probabilistic theories do not link causality with regularity and they claim that causal relations can exist also without the existence of deterministic laws.

Causal theories of production understand causes as specific tools for achieving effects. The key term here is manipulation — by manipulation with causes, required effects can be reached or undesirable effects can be avoided.

Theories of transfer causality in terms of production relation originate from the model of causal transfer formed by Descartes: if X causes Y, characteristic X is transferred to Y. Transfer models are used during physical explanation and on their basis mechanical theories of causality were formed (Psillos, 2007). For example Newton's theory of standard mechanics originates from this form of causality explication, while its predictive strength is high. It is a deterministic theory according to which the position and dynamics of each article of closed and final physical system in time "t" together with energetic system characteristics exclusively determines the physical system. The position of every particle is given by three axes as well as the dynamics is given by three axes, so the complete state of n–particles physical system can be defined according to six axes of n–particles. This system exists in 6–n dimensional space. The development of a closed system, or its history, present and past, can be presented in curve of this way dimensioned space which is linear transition between individual system states. If we have enough information about the initial state of the physical system and its dynamic characteristics, we can form accurate predictions about all potential states of this system by using mathematical calculation methods. Thus standard mechanical physical theory enables clear empiric predictions.

Hempel derives from the probabilistic theory of causality which enables to form inductive–statistic predictions. Those primarily originate from deductive–nomological way of explanation but laws have the form of statistically determined probability. This way explicated events cannot be understood as necessary implications of laws and additional conditions (standard D–N model) but only as to certain degree probable (to certain level confirmed). The conclusion of every in this way structured argument is a prediction if it is related to an event, which occurred only after the argument formation. There is certain symmetry between explanation and prediction — to explain the event by deducing from the laws and additional hypotheses simply mean to show that on their basis the examined event is predictable and expectable (Hempel, 1965). According to R. Carnap, the function of scientific law, which is given by one of the premises of D–N model, is to explicate the examined phenomenon and at the same time enable the so–called prior predictions — predictions of the facts, which have not yet been observed (Carnap, 1966). However, within the inductive–statistic prediction it is often necessary to take into account a number of conditional circumstances. An example is the prediction of the return of the Halley comet, which was formed by Clairaut in 1759. Using a simple extrapolation of previous observations it was predicted that the comet will reach the closest point in respect to sun (perihelion) in the middle of 1759. In conflict with this general opinion, Clairaut assumed the return of the comet few months

earlier because he took into consideration also the gravity effect of Jupiter and Saturn, which influenced its motion. This prediction was later confirmed by an observation (Forster, 2008).

9.3 Probabilistic Predictions and the Problem of Probability

In case of the theory of quantum mechanics, in contrast to standard mechanics, we cannot rely on the theories of transfer causality but on the probabilistic causal relations based on which the predictions of scientific theories have probabilistic character. The question is not what the theory predicts but to what degree the theory managed to form predictions that correspond with the observed realities. The term predictive accuracy defines the strength of the theory in probability prediction of observed events which is formally marked as $P(e|h)$, where e is the observed event, h is the theoretical hypothesis. $P(e|h)$ is the probability h in relation to e. Also the standard D–N explanation model can be understood as a special case of probabilistic prediction where h implies e (the value of probability is 1).

The term of probability is connected to two meanings — statistic, which is related to the stochastic character of coincidental events, and epistemic, which is connected to subjective degree of belief in probability of certain phenomena. The classic definitions of probability include also the P.S. Laplace's axiom, according to which, probability is a ratio of the number of positive cases to all potential cases. This statement is based on the assumption that all considered cases are equally probable if the information, that would disprove this belief, is not available. Thus to make the values of probability possible to determine, all equally possible cases are considered equally probable. The principle of belief in the same probability of all possibilities, if we do not have the reason to change this belief, is called principle of insufficient reason or principle of indifference.

A. N. Kolmogorov founded fundamentals of mathematical explanation of probability and defined its formal characteristics: (1)

for every event A, the probability is higher than 0; (2) if the event A is sure, its probability equals 1; (3) the probabilities can be summed up, if events A and B cannot happen at once, it is valid that: P(A or B) = P(A) + P(B) (Galavotti, 2008).

Within the science philosophy, there is a number of probability theories (frequency, inductive, propensive, subjective, and other), which develop one of two moments of the probability term — statistic or epistemic. For example, logical probability comprehends probability as a logical relation between argument propositions. It calculates the probability of a proposition, (e.g. hypothesis) in relation to another proposition (e.g. to proposition which is a confirmed observation verdict) which partially results from it. This form of probability term explication is a development of epistemic approach, according to which probability relates more to our cognition of facts than the facts themselves.

For the supporters of the subjective interpretation of probability, the degree of partial resulting equal to the degree of the subject's belief in the hypothesis validity. Thus the probabilities are — in contradiction to the logical interpretation — subjective degrees of belief.

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10. Scientific Experiments

Keywords: *experiment, experiment methods, errors elimination, experiment results validity*

10.1 Introduction

Scientific experiment is a systematic observation, which is performed under precisely defined conditions. These can be systematically varied and quantified. The basic aim of the experiment should be the discovery or confirmation of a new mathematical formula or law, which would link quantitative causes with their qualitative effects.

Within an experiment, the natural or artificial systems are set into artificially created conditions, which are created with the objective to allow the experimentalist to manipulate, monitor, record the occurring processes or in another way interfere with them. Hence, the main characteristic of scientific experiments is manipulation with empiric phenomena. The experiment method was one of the main features of the science of seventeenth century. However, under the influence of logical empiricism the attention focused more on the problems of theoretical cognition, deductive–nomological character of scientific explanation and logical structure of observation statements, while the status of observation and experimenting was not questioned. In contemporary scientific theory, main attention is dedicated to questions of the experimental activity character and its ontological, epistemological and methodological implications.

10.2 Epistemological Character of Scientific Experiment

The first step of experimental examination is the division and analysis of the complex phenomenon into simpler parts. It allows determining which characteristics, states or effecting forces are relevant for the phenomenon, which is the subject of examination. Reasoning processes of idealization are applied here and abstract models of examined phenomena are formed. The extend of this analysis depends on the aim of the experiment. In every experiment there is an infinite number of factors which can influence the examined phenomenon and in that way manipulate the experiment results. It is only experimentalist's decision when to stop the analysis because he is convinced that all manipulation and background noises sources are identified and eliminated. This decision usually underlies the stability of collected experimental results. The second step is the implementation of parts separation, which were selected on the analysis basis. The experimentalist can either search for the natural conditions that enable the separation, or artificially create an environment in which he can separate the interfering inputs. (compare section 10.3).

The character of experimental research can have double sense — examination of the causes of the given effect or examination of the consequences or characteristics of specific causes. J. S. Mill presents two basic methods of experimental examination (Mill, 1950):

Method of agreement — consists of comparison of various cases, in which the examined phenomenon occurs ,

Method of difference — the cases of the examined phenomenon occurrence are compared with cases, which are similar in

other aspects with the exception of the examined phenomenon occurrence.

Methods of agreement are implied by a rule: if two or more cases of examined phenomenon occurrence have only one condition equal, this condition is the cause of the examined phenomenon. A rule results from the method of difference: if the case of the examined phenomenon occurrence has all conditions in common except for one with the case, in which the examined phenomenon does not occur, this condition, which both cases differ by, is the cause of the examined phenomenon or inevitable part of the examined phenomenon cause. These two methods are very similar in many areas, but there are many differences between them. Both are methods of elimination — successive elimination of number of conditions accompanying the examined phenomenon in order to determine which of them can be omitted without influencing the examined phenomenon. The method of agreement is based on the statement that anything that can be eliminated is not connected with the examined phenomenon by any law. The method of difference claims that anything that cannot be eliminated is linked to the examined phenomenon by law. Within the experimental activity the so–called joined method of agreement and difference is often used which is based on the statement: if two or more cases, in which the examined phenomenon occurs, have only one common condition, while two or more cases, in which the examined phenomenon does not occur, do not have any common condition except for the absence of the previous condition: the condition, by which the two sets differ, is the cause of the examined phenomenon.

Not every type of manipulation with empiric reality is an experiment. The scientific experimentation is characterized by the stability and reproductibility, which requires certain level of control over the experimental environment. The level of control changes within the individual forms of scientific examination — laboratory physical or chemical experiments allow controlling the progress of the experiment to such degree, that the examined phenomena in the experiments can get to a stage of identical states. Despite that the objects of examination in biology, medicine, psychology and other social sciences are so complex and unstable that it often is not possible to repeat the experiment under the same conditions, the degree of control over the experiment conditions is low here. For this reason there are model groups of experimental objects created by the use of statistic methods, where the same average indicators of the basic characteristics are assumed. Then, the predictions derived from the theories are tested on these groups. The key difference between natural and social sciences with regard to the experimental cognition rests in the fact that while in the first case the statistic methods are used primarily in the tests evaluation and linking of the experimental data with theoretical assumptions, in the second case statistic methods play an important part during the constitution of the experimental data itself (Pfeifer, 2006).

10.3 Methods of Errors Eliminations in the Experiments

Many problems with the accuracy of experimentally measured values are related to the fact that it is not possible to measure only one independent parameter in one measurement. On the contrary, every examined phenomenon is rather a result of simultaneous effect of various forces. The task of the experimentalist is to find a way how to analyze individual active forces and subsequently measure them in the most accurate way. For example, if the aim of the experiment is to measure the expansion of liquids caused by heat, the experimentalist places the examined liquid into the pipe of thermometer and monitors how it rises at increased temperature. However, not only the temperature of the liquid is rising but also the temperature of the glass, so what we observe as a liquid expansion is in reality a result of the difference of the glass expansion and liquid expansion. There are several methods how to separate unimportant effecting forces within an experiment, measure relevant forces and that way gain valid result (Jevons, 1874):

Method of error avoidance — the experimentalists are trying to find such form of experiment execution within which they can avoid an error or they measure only fractional deviation. For example, measurements in astronomy are deformed depending on air temperature and pressure. Therefore, scientists always try to perform measurements in a moment when the examined cosmic object is in the highest possible point of its daily course, in meridian, because with such measurement the influence of the atmospheric refraction is almost completely eliminated.

Method of difference — is a way of leading the experiment where all interfering phenomena stay constant and only the object of examination is changing. In one experiment it can be observed, in the second (under unchanged conditions) it is absent. The difference in the results of two observations is calculated. This method of experiment is feasible on condition that not precise amount or size of examined objects is needed to be measured, only the difference between them. This procedure is applied, for example, during substitution measurement, where it is possible to determine the equality or inequality of the weights of two different objects almost without deviation. If we place two objects A and B on the scale so that the balance arms show balanced state, we cannot be sure if the result is not given by the incorrect balance of the scale arms or their different length. However, if we replace object B by object C, while the scale stays intact, we can see that C causes the same state as B under the same conditions. The causes of the incorrect measurement (if they exist) would stay the same; therefore it can be assumed that the weight of object B must be equal to object C.

Method of correction — experimentalist estimates the size of the interfering force in advance and based on that modifies the results of the experiment. This procedure is applicable only in cases where the irrelevant forces are constant or accurately countable. Then it is sufficient to subtract/add the forces estimated amounts from/to the result. For example, changes in the height of the bar in barometer are partially caused by the mercury temperature change but the coefficient of absolute dilatability for mercury is precisely given — can be found in a table where these data are considered and we can then adjust he formerly deformed results.

Method of compensation — the experimentalist avoids the interfering forces by creating forces of the same size but opposite direction. In that way the undesirable interference is eliminated. Galvanometer works in similar way; it measures the size of current by deviating the hung magnetic pointer. The resistance of the pointer is partially caused by direct influence of Earth magnetism and can cause measurement errors. Therefore, there usually are two identical pointers connected poles of which point to opposite directions while one is connected to a coil with current. In that way the pointer are indifferent (astatic) in regard to the Earth magnetism because they balance each other precisely.

Method of reversal — the experiment is purposely modified in such way that the interfering force will present itself in series of try–outs in opposite directions, while the average measured value of examined force is not influenced by the interfering force. So if we have two experiment results, out of which one is extremely big and the second is extremely small, interference equals half of the difference and the correct result is the mean value of previous measurements. Such measurements are possible to perform for example at the experiments with sound speed, which is transferred between two measuring stations by air. The cause of the measurement errors is usually the wind. This factor can be eliminated when the sound signals from each station are sent in different direction. The wind will speed up one of the signals and the second will be slowed down. The measured mean value of the sound speed will be freed from undesirable interferences caused by the wind.

10.4 Types of Experiment Results Validity Review

I. Hacking introduced a question how we can distinguish a valid experiment result from the artefact created by the experimental tool

(Hacking, 1983). He admits high level of the machine device by the load of its constitutional theory. For example, based on the theory of light, many various types of microscopes are designed (standard, polarisation, fluorescence, interference, electronic, and other). Despite this load by theory some examples from scientific practice show relevant results obtained by observation under the microscope. They can represent experimental basis based on which the theories about the observed phenomena are changed. On the other hand, if we manage to experimentally observe effects predicted by the theory, the validity of the experiment is strengthened and the correct functioning of experimental tools is confirmed. Another type of experiment confirmation is independent confirmation by different devices (e.g. electron microscope or polarization microscope). Different devices work on different principles and with different deviations, therefore, it is hard to imagine that the disperse pattern presented by different devices is only coincidence. Confirmation of the experiment validity and correct calibration of the measuring devices can be reached also by duplicating the implemented experiment or by proving that potential sources of errors are eliminated and the alternative explanations of collected data invalid (the so–called Sherlock Holmes strategy) (Franklin, 2012). Another form of proving the experiment results validity is using the results and methods themselves as an argument of their validity. For example, R. Millikan, who measured the electron charge, argued for his findings by the number of observations, which he repeatedly performed (thousand–two thousand experiments and which every time confirmed his assumptions (Millikan, 1911). Another way is use of independent, still valid theory, which explains the results of the experiment, while it indirectly confirms them. Also the statistic arguments working with the probability measure of the certain events occurrence can be used for validity confirmation. The presented forms of experiment validation are mostly combined to avoid incorrect findings and from them resulting invalid conclusions in the highest possible extend.

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11. Empiric Research in Social Sciences

Keywords: *social sciences, qualitative and quantitative methods, empiric research, reliability, validity*

11.1 Introduction

The status of social sciences and their methodological instrumentarium is the subject to various discussions and open questions. One of the basic questions is the one, whether it is possible to include social sciences into methodological scope of natural sciences (dispute of naturalism and anti–naturalism). Another problem is the nature of explanation within social sciences. It concerns the standard deductive–nomological model, description of causal relations, or does the explanation of social phenomena rather have character of interpretation, search for significance or meaning? Another complicated relation is the one between the theoretical model and empiric world of social phenomena to which it is related. This relation is problematic also in case of natural sciences, which are based on various quantitative methods and explanatory mathematical models. It is even more complicated to interpret in abstract language the data collected by qualitative methods, which apply to the examination of individual cases. Can we form rules of correspondence in social studies which would define the relation between theoretical and observation terms? The open question is also the specification of entity types which the social sciences work with — are they individual irreducible social entities or it is possible to reduce them to individual entities (dispute of holism and individualism)?

11.2 Specific Position of Social Sciences

The vagueness in methodology of natural sciences results from their open character: social phenomena form also other types of effects (e.g. physical, chemical, biological etc.). Therefore, according to D. Davis, the social explanations are incomplete in a radical way compared to the explanations of natural sciences (Davidson, 1984).

The supporters of anti–naturalistic view argue that social phenomena are only vaguely connected to physical phenomena because there is an unlimited number of physical implementations of social phenomena. Therefore, it is not possible to generalize the behaviour of social entities in a form of natural laws. The opposite opinion, presented by J. Searle, postulates the world as a unified phenomenon. Any divisions or classification of reality that are created in everyday life, are purely arbitrary. It is the same problem as with the division of the universe into sphere of mental representations and the sphere of material entities. Searle rejects such division as something proofless, derived mostly from specific tradition. As an example he presents situations, where our learnt (or inherited) division of phenomena into mental and material, fails. Is, for example, the elections result something mental or physical? Or the points gained in sport competition — do they have material or mental character? Searle considers similar questions a proof of unsubstainability and arbitrariness of dual understanding of the reality (Searle, 2002).

The supporters of naturalistic understanding of social phenomena understand social entities as on principle reducible to simpler entities. Such reduction is applied in natural sciences, where theory A is reduced to theory B provided that it is possible to prove that all phenomena explained by theory A are explainable by theory B. An example of reductive explanation of the term "temperature" (valid within the Boyle theory of gases) is the term medium kinetic energy of molecules (valid within Newton's laws of movement, compare section 6.4). Searle distinguishes several types of reduction. The important factor is the difference between two types of reduction: eliminating and non–eliminating. If a phenomenon is explained by the use of eliminating reduction, it means we prove that this phenomenon was only an illusion. In reality, there is nothing as sunrise or sunset; this phenomenon was reduced by elimination within the scientific theory. Despite that, there are scientific theories which explain the examined phenomenon by its reduction to another phenomenon (e.g. solid state is explained by specific movement of molecules in a certain type of a grid) but this phenomenon retains its sustainability within the theory. It is not only an illusion but a real characteristic of the subject reductively explained by causal effect of its microstructure. In this case the non–eliminating causal reduction is applied (Searle, 2007).

11.3 The Problem of Qualitative and Quantitative Methods in Social Sciences.

The ambiguities related to the status of social sciences are reflected in the existence of two paradigms — qualitative and quantitative. Qualitative paradigm sees the basis of social sciences in forming interpretations, not explanations. Human behaviour is not possible to explain but it is necessary to try to understand it from the position of the person involved. It prefers subjectivism and direct, uncontrolled observation. From the methodological perspective it focuses on qualitative methods such as ethnography, studies of individual cases, depth interviews, and interviews with members of selected group, long–term observation, texts and documents analysis, unstructured interviews, detailed audio and video transcripts. Within the quantitative paradigm, the preferred methods are inductive procedures, methods leading to knowledge expansion and new discoveries. Its other characteristics are holistic understanding of reality, focus on the individualities (studies of individual cases — case studies), descriptive nature, focus on procedure.

The contrast between qualitative (QUAL.) and quantitative (QUAN.) is postulated in a form of preferring: long–term observation (QUAL.) to forming random samples during social surveys (QUAN.), analysis of text and documents (QUAL.) to experiments, unstructured interviews (QUAL.) to official statistics (QUAN.),data analysis without in advance defined variables and categories for quantification of collected data (QUAL.) (Hanzel, 2009). This conflict between the two paradigms can be understood also from a broader perspective as a conflict of naturalistic and positivistic paradigm.

Naturalistic paradigm (NP) views reality as a heteromorphic, constructed and a holistic one. The observer and the observed are in mutual interactive unity while it is very difficult to break the network of mutual causal connections and distinguish the causes from their effects. According to the positivistic paradigm (PP), the reality is unified, tangible, possible to analyse and quantify. There is an exclusive relation between the observer and the observed, they are each independent, therefore, it is possible to form laws which are generally valid (independent on specific time and place context. The key factor is the existence of precisely defined criteria, objectivity of which is given by the possibility of quantification (measurement). The question is, whether it is possible to understand these two paradigms as reciprocally complementary, or whether they are different in such degree that it is not possible to merge them within one unified methodological instrumentarium. Is social reality describable in terms of objective (measurable) variables, or is it possible just to interpret her in a specific subjectively

dependent way, while such interpretation always depends on specific (original) conditions and on specific time frame (the same situation can never happen again)? The problem of the description versus interpretation is one of the key characteristics of the research in social sciences.

11.4 Structure and Characteristics of Empiric Research

The first phase of research within the social sciences is its planning and organisation. Research starts with stating the basic aims. From the aim point of view, the research can be divided into:

- theoretical — in which the attention is paid to cumulation of theoretical knowledge, detection of their basic axioms, postulates and consequences, comparison of individual theoretical procedures, searching for mutual conflict points, examination of internal consistency of theories, etc. The main thinking processes are deduction, analogy, modelling comparison, etc.;
- exploration — which searches for new dependences, test new predictions resulting from theories;
- verification — focusing on the verification of observation statements resulting from theoretical hypotheses;
- diagnostic researches — which focus on defining the status of things or events, specification of their characteristics and detection of the characteristics' causes, depending on the object of their examination they are divided into heuristic (define the characteristic or set of characteristics of an object or phenomenon) and verification (verify determined diagnosis e.g. based on the comparison with existing group).

The research process is derived from following steps. Firstly, a specific problem is identified and its solution becomes the main aim of the research. Within the theoretical analysis, we try to define the problem more precisely and include it into the structure of existing explanations. The result of this study is postulating of certain relations which has the character of scientific hypothesis.

Then the process of logical and empiric hypothesis verification follows, which results in confirmation of disproval of postulated relation and leads to including the findings into the structure of current knowledge. Depending on the significance of the discovered postulate, if appropriate, it is followed by modification (in an extreme case even elimination) of certain theoretical statements. The research process can be divided into four main parts:
— theoretical models analysis,
— research procedure:
— research problem (hypotheses, indices, variables),
— research methods (tools, techniques),
— empiric research (hypotheses verification tools),
— conclusions (descriptive, explanatory, predictive).

Scientific hypothesis is an assumption aim of which is the explanation of certain phenomenon or a set of phenomena. The condition of a valid hypothesis is such statement about the matters status from which the experimental predictions can be derived (compare section 7.2). Hypothesis is subject to verification process (or falsification), result of which is either its confirmation (or corroboration), or disproval. Hypothesis postulates the dependence between variables. Within the statistic evaluation we distinguish zero hypothesis (denote homogeneity and independence) and alternative hypotheses (denote variability and dependence).

The variables in hypotheses represent such characteristics and features which can vary within the examined group depending on the circumstances. There is a great number of criteria based on which the variables can be divided into various groups. The basic division, which results from the hypothesis structure, is divided into independent and dependent variables. Independent variable is a variable which does not is a subject to the impact of other variables. Independent variable influences values of a dependent variable. For example, in case of the hypothesis "Cinema attendance", it decreases with increasing age. We work with independent variable, which is the age of the cinema visitors, and with dependent

variable, which is the number of visits. Based on the number of variations which a variable can acquire, we distinguish two–valued variables (e.g. sex) and multi–valued variables (e.g. type of transport). Variables can be also continual (a variable acquires the values from continually structured set) or discrete (among the values that a variable can acquire, are no mean values — e.g. a driver — not a driver). Indices are created by operationalization of the variables so that the measurable characteristics of the examined objects and events are extracted from the variables. For example, the variable "social position" within the work team is operationalized when we define it as a "number of votes gained in the surveys". This information is quantified. Such procedure is performed mostly within statistic method of data elaboration.

Research tools are examined from their reliability perspective, the reliability with which they measure what they measure. Reliability can be examined e.g. by series of repeated measurements subject of which is the stable, constant value of the variable. If the research tool is reliable, discovered values should be also stable and constant. Other possibility of testing the reliability is the so–called parallel form of reliability estimate where the found values correlate with the values measured by other equivalent tools. For example, if test A measures the same value as test B, the test reliability can be estimated as the degree of both tests results agreement (Ferjenčík, 2000). Validity of the research tool shows that it really measures what it should measure. It determines the degree of agreement between the discovered results and characteristics which were planned to be observed. If the research tool is not reliable, it cannot be valid. There are three main types of validity distinguished: contextual (determines whether the contents of the measuring tool corresponds with the characteristic that should be measured), criterion validity (determines the degree of agreement between the existing criteria or standards and the results obtained by the means of research tool), and construct validity (determines the degree, to which the measuring tool actually represents specific theoretical construct e.g. by comparing the agreement degree of theoretical predictions and collected data (ibid.).

In general, the scheme of empiric research, performed by the form of statistic data(quantitative research) elaboration, can described in the following steps (Juszczyk, 2003):

Research planning and organisation — in this part the research aims, problem and hypotheses are defined; the subject, group or unit of the research are determined; the dependent and independent variables (quantitative and also qualitative) are determined; the type of research is determined (complete or partial, representative, which can be either selected on purpose or randomly); the measuring scales are determined and the research tools are prepared.

Empiric research — the pilot research (pre–survey) and the basic research (either directly or with the help of survey assistants) are executed.

Results elaboration — includes the control of collected material; material classification into typological (quantitative) and variation (qualitative); calculation of the data; results elaboration in form of statistic tables, graphs, sets, diagrams; determination of the degree of central tendency (e.g. median); calculations of the scatter degree; determination of correlation between variables and determination of the forces and statistic significance

Statistic analysis — analysis of representative sample results of which lead to the confirmation or elimination of determined hypothesis.

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Dictionary of Terms

Science — system of knowledge representing the laws of objective reality and serving for the purpose of explanation, prediction and modification of reality.

Scientific method — empiric process of discovery and demonstration, necessary for scientific examination. It mainly includes phenomenon observation, hypothesis formulation about the phenomenon, set of experiments that will prove or disprove the determined hypotheses, and forming of conclusions that confirm, falsify or modify the hypothesis. Scientists use scientific method for searching the cause–effect relations in nature. They proceed according to the observation — prediction — testing — generalisation principle.

Scientific theory — explanation of the set of related observations or events based on the confirmed hypothesis and multiple–times–verified independent groups of researchers.

Critical thinking — mental process which is applied in science and includes cognitive processes of theoretical generalization, experiment construction, hypotheses testing, data interpretation and scientific examination.

Induction — process of general principles derivation from individual facts and cases. A form of argumentation which proceeds from empiric premises to empiric conclusions, while conclusions are not directly deductively derivable from these premises. Inductive arguments are therefore a type of expanding argument, in which, based on the principle of probability more is derived than it is contained in its premises. Premises are the basis of conclusion, but the conclusion does not necessarily result from them.

Deduction — mental process, in which the conclusion necessarily results from the premises and, therefore, it cannot be incorrect if the premises are correct. Deductive argument proceeds from general laws to individual cases.

Explanation — set of statements, which explain the existence or occurrence of objects, events or state of things. The most common forms of explanation include ***causal explanation, deductive–nomological explanation,*** which means including the explanandum (object of explanation) into general statement, from which it can be derived by means of deductive argument, and ***statistic explanation,*** which means including explanandum into the general statement, which is formed on the principle of induction.

Causality — relation between two simultaneous or consequent events, where the first event (the cause) invokes the second event (the effect). In case of causal relation, a rule must be valid that when one event occurs, it produces, invokes, or determines the second event. If a phenomenon occurs, the second (necessarily) occurs, as well.

Scientific methodology — deals with the problem of science nature, science problem and scientific thinking problem.

Methodology — discipline about methods and science principles

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