

Inductive and Deductive Methods in Cognition*

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March 30, 2002

Elements of Logic

The need for development and application of reasoning methods and techniques that allow for acquisition of new knowledge based on theretofore available knowledge was realized by scholars in ancient India and Greece at about the same time – as early as in the 6th century B.C. Later on, the science of rational reasoning had been named logic (Gr. *logos* = word). The first scholars to attempt formalization of rational reasoning were Democritus, Socrates, and Plato (4th century B.C.). Foundation of academic formal logic has been validly credited to Aristotle (384-322 B.C.). Aristotelian formal logic underlies the methodology of Western science. The system of methodological techniques and tools that facilitate generation of scientific knowledge is called epistemology (Gr. *episteme* = knowledge). While logic deals with individual stages of knowledge evolution, epistemology investigates complex mechanisms that interconnect logical elements of knowledge evolution in ongoing processes of knowledge acquisition. The founding fathers of Western scientific methodology were F. Bacon (16-17th centuries, empiricism), R. Descartes (16-17th centuries, rationalism) and I. Newton (17th century). Logic as a science underwent revolutionary changes in the early 20th century due to development of mathematized, symbolized forms of logical transformation, which further gave rise to mathematical,

or symbolic logic developed by George Boole, Charles Pierce, Gottlob Frege, Bertrand Russell, Alfred Whitehead and others.

Mathematical logic stepped in at about the same time when inductive methods for rational reasoning, theretofore dominating in Western scientific methodology, were on decline. As a result, a new – epistemological - trend in scientific philosophy took on the development of innovative and more efficient approaches and techniques in inductive logic in an effort to bring the empiric inductive methodology back to the leading position. Thus, the new sections of inductive mathematical logic had emerged.

Sequential logic, for instance, is aimed at development and systematization of rules and techniques for inference of new knowledge from premises. Traditional canons of the formal classical logic of premises, as imposed on sciences generally operating with complex, multi-semantic notions, were not adequate for that purpose. Much of the credit for development of sequential logic lies with the works of C. Lewis, B. Ackerman, A. Andersen, and N. Belnap. Sequential logic still remains one of the most dynamically developing areas of logic.

Unlike classical two-valued logic, multiple-valued logic operates with a certain spectrum of intermediary values positioned between truth and falsehood. In this paper, I refer to a scale of multiple values as “validity level”. In other contexts, the term may refer either to a substantiality degree of obtained knowledge, or to a relative content of truths and fallacies in it. Development of multiple-valued logic was pioneered by Ya. Lukasevich and E. Post.

Another area within inductive logic is probabilistic logic, for long time developed by

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R. Carnap, a founder of neo-positivism. Probabilistic logic analyzes truths and fallacies of inductive inferences through probability theory.

In the late 20's of the past century, J. Lukasiewicz and C. Lewis laid the foundation of modal logic dealing with the notions of necessity, possibility and incidence. B. van Fraassen, a contemporary philosopher, has made a further significant contribution into modal logic.

Other types of logic are: epistemic logic (study of logical relationships between refutable, unsolvable, provable, etc.); logic of evaluation (study of the rules for construction of logical relationships between evaluating statements); causal logic; logic of change; deontic logic (logical study of normative relationships), and others. All of these logical systems are interconnected in a fairly complex way.

Mechanisms of Acquisition of New Knowledge

Within the traditional framework of formal logic, transformation of knowledge occurs along two lines conventionally referred to as deduction and induction. Deduction (Lat. *deductio* = leading away, drawing out) is aimed at particular phenomena, whereas induction (Lat. *inductio* = leading or bringing into, introducing) is aimed at general truth.

There are two main criteria that draw a line between inductive and deductive techniques and rules. One of the criteria is strict, i.e. allows no exceptions. It determines whether or not transformation of information yields a lower validity level. Logical systems that do not involve a decrease in validity of information under transformation are called deductive. The stages of information transformation that result in a lower validity level are called inductive. This criterion is effectual for individual, isolated logical systems but not for complex structure processes of scientific and "common" reasoning. At that level of reasoning methodology, another criterion of differentiation between inductive and deductive logical steps is applied, which is a non-strict criterion. It determines the direction of knowledge transformation within a totality

(conjunction) of particular premises and generalizing universal premises (laws or rules).

Deduction

Deductive techniques of formal logic are always leading from the general to the particular and never vice versa. Inductive approaches, with a few exceptions, are aimed at an opposite direction, from the particular to the general, and allow for generalization and augmentation of existing knowledge. The fact that deductive approaches of formal logic are based on transformation "from the general to the particular" does not mean that a deductive logical mechanism necessarily produces a singular, particular statement. However, the generalization level yielded by deductive transformation cannot be higher than the original level of generalization of input information.

The ability to maintain a given validity level is a unique virtue of deductive systems: it allows to combine various deductive elements into complex compound structures based on various non-obvious particular inferences derived from a set of general premises. Verification of truthfulness of each of particular statements can indirectly provide an assessment of a general level of validity of initial premises. This kind of assessment does not, however, warrant the truthfulness of all initial premises – even in the event that most of the possible inferences are verified as truthful, there may always be left at least one false inference among those that remain unverified, while for a conjunction of initial premises to be fallacious, it needs one false inference. To overcome the effect of such an asymmetry between confirmation and refutation, Karl Popper proposed the famous demarcation criterion that separates the scientific from the unscientific.

Complex processes of cognition, including scientific theories, with their logical structures representing a composite deductive ("from general premises to particular inferences") mechanism, are referred to as axiomatic-deductive if they are based on axioms (Euclid's geometry, Newton's mechanics), or hypothetical-deductive if they are based on a

totality of hypothesis as initial premises (the theory of special relativity).

Axiomatic-deductive cognition is employed not only in scientific theorizing. Traditional computer programs represent a clearly expressed deductive algorithm for drawing particular inferences from a totality of initial premises – both imbedded in a program and stored in a database generated by a user. Axiomatic-deductive way of thinking is also characteristic of dogmatic-type individuals whose reasoning is based on dogmas postulated either by commonly accepted scientific theories or by scriptures and divine revelations.

Induction

Inductive approaches to logical transformations allow for expanding and condensing existing knowledge by adding to it a newly obtained knowledge. Formal inductive logic applies the techniques that allow for generalization of individual particular statements and, thus, production of statements of a more general character by expanding a multitude of described objects (generalizing induction), or for expansion of existing knowledge by particular statements contained in initial knowledge in a non-obvious form. According to John Stuart Mill, the term “induction” only applies to an inference of an unknown instance or a multitude of instances based on observation of known instances.¹

Inductive methods tend to degrade the validity level of knowledge in the end of each inductive transformation step. Therefore, the validity of initial premises upon inductive transformation in no way warrants the validity of obtained inferences.

The works by F. Bacon², J. Herschel, J. S. Mill, and M. I. Karinsky have tremendously pushed forward the development of the system of inductive logic. A contemporary philosopher R. Carnap has made a great input into inductive logic. There exist various techniques for inductive transformation of knowledge, each with its special features. In this context, it should be important to briefly define the following ones: generalizing induction, inference by analogy (analogy), and cause-and-effect induction.

Generalizing Induction

Generalizing induction is, probably, the most important of all inductive elements. At early stages of development of formal logic, generalizing induction was identified with the logic of induction. Explaining the meaning of induction, Aristotle wrote: “...induction is a passage from individuals to universals”.³

There exist two classes of elements of generalizing logic: incomplete non-statistical and incomplete statistical induction. Statistical induction is generalization of a frequency of occurrences of a certain character in a narrow class of objects (phenomena) onto a wider class of objects.

Analogy

The analogy approach in inductive logic allows for obtaining new information based on comparison with a specially selected analog. An analog may be either another object with a certain set of similar properties or a specially designed ideal model. Inductive analysis “by analogy” (analogy analysis) allows for making propositions of a fairly high degree of validity as to the presence of theretofore-unknown features in an object based on the fact that such features are present in its analog.

Cause-and-Effect Inductive Elements

In formal logic, there also exist sets of techniques and rules that allow for establishing causes based on analysis of their effects. As well as other inductive elements, the cause-and-effect analysis produces enriched output information, however, with a lower validity (truthfulness) level. A decrease in validity depends on a method of input data processing. Minimization of the loss of validity may be achieved through following a whole set of requirements fairly well developed both for traditional formal logic and for various subjects of mathematical inductive logic. A neglect or improper use of those methodological requirements results in malfunctioning of an inductive mechanism and in *a priori* invalid output information.

Hypothesis

A hypothesis (Gr. *hypóthesis* = supposition) is an assumption that is neither derived by a

scientific-inductive method from empiric effects, nor deductively inferred from initial premises. Hypothesis is a special, alogical mechanism for obtaining new knowledge. A hypothesis may be a result of intuitive revelation, consecutive or random examination of assumptions made by adducing experimental (or anticipated experimental) results for theoretical conclusions, etc. A hypothesis that represents a self-evident assumption is usually called an axiom.

Descartes' rationalistic cognition method is different from Bacon's empiric method only in the part allowing the use of self-evident, axiomatic assumptions verified through deductively inferred effects. Discussing the rigid requirements to this type of hypothesis, Descartes wrote, "By intuition I mean, not the wavering assurance of the senses, or the deceitful judgment of a misconstruing imagination, but a conception, formed by unclouded mental attention, so easy and distinct as to leave no room for doubt in regard to the thing we are understanding."⁴

In general, hypothetical elements structurally resemble the inductive elements, implying however quite a low validity level of output knowledge. Therefore, each hypothetical element in a system of scientific cognition requires a deductive verification of as many inferred effects as possible.

Methodological Systems of Development of Scientific Knowledge

A system of cognition based on inductive elements represents a complex composite structure, in which a multitude of highly valid observations are transformed into generalized laws and models, often capable of explaining a given variety of observed facts. At every stage of inductive generalization and knowledge augmentation, newly obtained knowledge is carefully, albeit selectively, experimentally verified. The larger is the number of verifications, the better is recovery of the validity level previously reduced during an inductive transformation.

The positions of early empiricism were based on presumption that a large number of special verifications are sufficient for bringing the validity level of inductive inferences back

to the level of truth. Modern philosophy views this approach as highly doubtful.

Strictly inductive forms of cognition have two significant flaws. Firstly, the low validity level of output information makes it impossible to guarantee that models and laws resulting from an inductive study are "correct"⁵. Secondly, an inductive process involves a successive immersion into the cause-and-effect conditionality of input data, which is fraught with encounters with specific inadequacies (insufficient experimental data, erroneous interpretation of experimental results, psychological factors, etc.) and may lead to a crisis of an entire inductive research program. To avoid the crisis and to temporarily keep the dynamics of a study, an arbitrary hypothetical bypass element may be introduced into an inductive system. This technique, although allowing for keeping the momentum of a study, causes a dramatic drop validity level, which makes a subsequent overall verification virtually impossible.

In classical empiricism, as formulated by a French philosopher Bacon, new knowledge is obtained through strictly inductive logic, whereas deductive elements serve as auxiliary verification tools. It was much due to success of Newton's works in natural sciences and epistemology, as well as Newton's bias against hypothesizing, that the empirical method for knowledge acquisition had dominated in natural sciences well into the late 18th century.

Descartes' rationalistic program of scientific cognition was in principle no more deductive than Bacon's empiric program. Its essential difference was the acceptability of individual hypothetico-axiomatic elements in inductive systems. Opponents of rationalism claim that because of the use of hypothetico-deductive elements in science and, therefore, dramatically low validity levels of resulting scientific theories, many theories created during several centuries did not acquire the status of scientific theories.

In the mid-18th century, some of the fundamental fields of natural sciences started developing signs of growing crisis. The perseverance in intensification of deductive studies and development of scientific knowledge had brought the sciences to the "hard rocks" depth at which formal inductive

logic mechanisms available at that time appeared inefficient. Advanced research programs that took the lead and focused on causal explanations of unobservable essence of the universes under study were experiencing a lack of experimental material – an inadequacy caused by the lack of means for observation and manipulation with micro-objects – resulting in failures of inductive mechanisms.

The said circumstances must be an explanation for the fact that in the mid-18th century, despite the strong bias against hypothesizing, there emerged numerous hypothetico-deductive theories that were based on one or more hypothetical assumptions. Based on conjunctions of principles underlying complex deductive theoretical schemes, inferences were made of the effects observable by the then available technological means. Experimental verifications of inferred effects were used to substantiate respective hypothetico-deductive theories. Some of the examples of hypothetico-deductive theories of that time are: Boerhaave's caloric theory, Boskovic's theory of matter, the LeSagean corpuscular theory of gravitation. The hypothetico-deductive methodological principle of development of scientific theories had been recognized as valid by as late as the mid-19th century, and mostly due to the epistemological works by LeSage⁶.

Having asserted its right of existence, hypothetico-deductive method had produced an abundance of various physical theories. By the end of the nineteenth century, in the field of gravity studies alone, there had been several dozens of gravity theories, as well as explanations for gravity based on aether theories⁷.

The rapidly emerging and oftentimes poorly substantiated hypothetico-deductive physical theories met with staunch opposition from the positivist faction within philosophy of science, whose chief concerns laid with the consequences of the ongoing deterioration in standards of scientific methodology. In 1920, a circle of philosophers of science, self-proclaimed as logical positivists, was founded in Vienna. Inspired by the new opportunities lying in non-classical inductive logic, they were set to revive empirical methodology and its inductive methods. Rudolf Carnap, Moritz

Schlick, and Otto Neurath were the best known among the founders of the circle. Each of these philosophers had his own and more or less independent perspective of the strategy for revival of inductive methods in science.

However, the strong critique of inductive methods in empiricism on part of Karl Popper, yet other great philosopher of the 20th century, had enhanced the arguments against the possibility of verification of inductive scientific theories. Popper denied the feasibility of verification of scientific theories and proposed his own demarcation criterion for the scientific and unscientific. According to Popper, the demarcation problem consisted in a quest for a criterion that would provide the means for discovery of the differences between empirical sciences, on one side, and mathematics, logic and "metaphysical" systems, on the other side⁸.

The impact of Popper's works was hard enough to shake the position of rational-inductive methodology. The members of the Vienna circle had to unite in order to defend their views.

Carnap's efforts on development and promotion of inductive empiricism were the most consistent ones made in the epistemological history of the 20th century⁹. W. V. Quine dubbed Carnap's works as the pinnacle of all the previous achievements of empiricism.¹⁰ However strong was Carnap's belief in inductive mathematical logic, his idea of building, based on new logical means, a solid scaffold, supported by sensual observations, for theoretical hypothesizing, has yet to be realized.

In the same years, Carnap's fellow member of the Vienna circle, Neurath, developed the naturalistic version of scientific development – encyclopedism¹¹. According to Neurath, scientific knowledge has no rigid structure but consists of non-rigid encyclopedia in the form of protocols of actual scientific discussions.

One way or another, the Vienna neopositivists supported the positivism refusal from exploring the cause-and-matter relationships, as well as from explanations and metaphysics. Hume wrote, "When we run over libraries, persuaded of these principles, what havoc must we make? If we take in our hand any volume; of divinity or school metaphysics,

for instance; let us ask, does it contain any abstract reasoning concerning quantity or number? No. Does it contain any experimental reasoning concerning matter of fact and existence? No. Commit it then to the flames: for it can contain nothing but sophistry and illusion."¹²

Regretfully, the long-time efforts made by proponents of empiric methodology for restoring the dominating positions of inductive logical mechanisms in the development of scientific knowledge have not succeeded, although many other views of radical positivism, expressed in the afore-cited Hume's motto, have received wide recognition.

In 1960, a historian Thomas Kuhn published his epochal work *The Structure of Scientific Revolutions*, stepping in the long-standing heated dispute between deductive and inductive methodologists¹³. Kuhn provided compelling evidences to the effect that the "beyond the logic" irrational factors greatly influence the formation of scientific views. Lakatos trenchantly labeled that type of factors as "crowd psychology". The effect of Kuhn's work on epistemology was tempestuous. A decade later, Feigl and Scriven showed on specific examples that many of the distinguished scientists systematically violated the norms and rules deemed scientific. From that time on, methodology of science has been in a state of the so-called rationality crisis.

Correlation between Inductive and Deductive Mechanisms at Various Stages of Western Civilization

Speaking of the interchanging dominance of inductive and deductive methods in methodological mechanisms for acquiring highly verified knowledge, one can mark out several consequential periods in human civilization. Below I attempt to contour those time frames and tentatively compare them with the rates of civilization progressive development in the respective historic periods.

1. From the Sixth Century B.C. to the Second Century A.D.

In the ancient times, the ground was broken for foundations of philosophy, logic, ethics,

physics, mathematics, mechanics and some other fundamental sciences. Both inductive (from the particular to the general) and deductive (from the general to the particular) methods were in use for the needs of idea substantiation. As is known, Aristotle believed the deductive methods to be superior and viewed mathematics as an exemplary science; however, in his works, there was an apparent predominance of empiric methods of reasoning – from particular observations to general laws and rules. Aposteriority, i.e. predominance of inductive logic was in general characteristic of the ancient Greek science.

At about the same time as the basics of logical methods of reasoning were developed in Greece, the problem of a proper use of logical means was a subject of debates in ancient India: "The merits of eloquence and logic were so undeniably recognized in (ancient) India, that for a pundit to elude an argument was a faux pas."¹⁴ However, unlike ancient Greeks, the Indian culture embraced the belief in an *a priori* acquisition of higher knowledge through the so-called 'enlightenment' – a special meditative state of consciousness, associated, according to currently accepted views, with a specific mode of functioning of the right hemisphere of the brain (while the left hemisphere is inactive). The traditional Indian Yoga, as well as the emerging Buddhism methodology practiced and popularized the methods for knowledge acquisition by means of intuitive enlightenments. This might have been a factor that determined the difference in the science advancement rates in the East and West in the end of the Antiquity Period and the dawn of the Christianity era.

2. 2nd to 14th Centuries. From the End of the Antiquity Period to Dark Ages.

The fall of the Roman Empire and establishment of Christianity had exposed the Western civilization to the brutal influence of dogmatic ideology effectively supported by the ubiquitous power of church. Methodological rules effectively enforced for obtaining highly valid knowledge were based on a radical dominance of axiomatic-deductive techniques aimed at deduction of *a priori* valid

knowledge from the holy books and the equally canonized works by selected philosophers of ancient Rome and Greece, Aristotle being in the first place.

In the course of numerous scholastic religious and philosophical discussions of that time, there had been developed and perfected the complex schemes of deductive transformations; however, the overall scientific progress was extremely sluggish. Industrial and military technologies were somewhat of an exception due to being the areas of human activities more than others involving observation and subsequent inductive generalization of experimental results.

The Dark Age millennium of the Western civilization was the manifestation of the gravest consequences of the imbalance in application of inductive-deductive mechanisms with the domination of axiomatic-deductive methods.

In general, the state of the art of the field of sciences in the Western civilization of that time was much behind the eastern countries. It is apparent that the gap was mainly rooted in the difference in the power of the corpuses of religious doctrines dictating the rules for knowledge acquisition.

3. 16th to 17th Centuries. Renaissance and Formation of Sciences.

The weakening of religious dogmas and the changes in methodological standards gave way to the renaissance of science. The inductive methods for cognition that did not deny but, on the contrary, widely used the deductive mechanisms for verification of obtained knowledge, were rehabilitated and came into dominance in the 16th century. The victory of inductive logic was made possible due to Bacon, Galilee, Newton, Leibniz and many other great scientists of that time. Even Descartes, the founder of rationalistic methodology unjustly represented as an opponent of empiricism, did not deny the importance of inductive methods for new knowledge acquisition, but supplemented them with specific axiomatic-deductive elements (the hypothetico-deductive method as such was developed much later).

Although the pendulum of preconceptions in methodology had predictably swung too far

to the inductivism side after a long period of dogmatism and scholastic deduction, nevertheless, the scientific knowledge development was quite rapid in the time of the apparent predominance of empiricism.

4. 18th Century.

The 18th century witnessed the start of the empiricism crisis, the first signs of which surfaced in the 40's of the 17th century. In the course of its two-century dominance, the naïve empiricism methodology itself had unknowingly turned into a dogma by gradually tightening the requirements for experimental substantiation of scientific theories in the direction of ascent "from the particular to the general", by denying the validity of the use of statements on unobservable entities in theories, and by understating or refuting the role of rationalistic methods for substantiation "from the general to the particular".

The most significant restrictions were imposed by orientation to substantiation of theories strictly by observation of objects under study. As long as science was dealing with surfaces of micro- and macrocosm, i.e. as long as objects of studies were those perceivable by a naked eye, it was feasible to comply with the observation requirements. However, by the mid-18th century as the knowledge in physics, chemistry, biology and other sciences was rapidly advancing, it appeared that the biggest progress had been achieved in those theories that neglected the then effective restrictions and were operating with hypothetical, unobservable entities *a priori* inaccessible to a naked eye – such as atoms, molecules, aether, electrical fluid, phlogiston, gravity-caused micro-corpuses, and so on.

Rejection of those theories out of methodological concerns despite the clear progress of the descriptive-predicative mechanism for theorizing caused a long-standing controversy between consistent empiricists and their opponents. As a result of decades of heated philosophical debates, the ideology of hypothetico-deductive method (then called the hypothesis method) had been worked out and officially acquired the status of science by the beginning of the 19th century.

One of the major arguments in justification of the hypothetico-deductive method was the necessity for boosting the scientific development, which – according to proponents of the method – would be impossible under classical empiricism ideology. David Hartley, whose neurophysiologic theory of ether fluids was rejected as being hypothetical, wrote in his famous book *Observation of Man* that if knowledge acquisition would ever need to surpass the snail speed, then the inductive system should have been supplemented by a variety of hypothetical methods¹⁵.

While I would not be able to make an overall assessment of the dynamics of scientific progress in all fields of science in the 18th century, it is certain that in fundamental physics of that time there was a noticeable slowdown as compared with the previous period.

5. 19th Century

Throughout the 19th century, there was seen a progressive dynamic in the development of sciences. One of the important factors of scientific progress, not so obviously expressed in earlier times, was the technological advance that allowed researchers to operate with objects theretofore inaccessible to human sensory organs. Microscopes, telescopes, electrical and radio devices dramatically expanded the scope of experimental investigations, which, in its turn, increased the number of scientific theories attempting to provide definitions and explanations for newly discovered phenomena.

The same time witnessed the qualitative leap in mathematization of fundamental sciences. According to T. Kuhn, the period from 1800 to 1850 was the time of the second scientific revolution caused by a deep penetration of mathematical methods of analysis into science¹⁶.

6. First Half of the 20th Century

The past century of our history is the most difficult for objective assessment of the dynamics of intensification of scientific knowledge. The factors that complicate even the most tentative analysis are: much faster industrial technology advancement than it was

in the 19th century, revolutionary growth of computing technologies, including mathematical methods developed in the first half of the 20th century, and emergence and evolution of computing devices in the second half of the century. Yet another and more important factor might have been a radical change in the attitude toward the fundamental science and its ultimate goals and the displacement of realism by instrumentalism.

The first half of the 20th century witnessed:

a) An explosive growth of the number of scientific theories brought by the scientific-technological revolution;

b) Creation of the relativity theory and quantum mechanics, as well as groundbreaking discoveries in other fundamental sciences;

c) Methodological prevalence of the hypothetico-deductive method due to the impressive achievements in relativism and quantum mechanics. The dominance of hypothetico-deductive methods was especially strong in fundamental sciences, given the insufficiency of experimental material. It was less so in applied sciences aimed at phenomenological generalization of experimental data.

d) Global mathematization of fundamental natural sciences nourished by the “fashion queen” of all fundamental natural sciences – theoretical physics. The overall spirit was well described by Volkenstein: “Although mathematization has always had to proceed from simplified models, its development has never been compromised. Mathematization is a win-win solution”¹⁷.

e) The change of perspective of fundamental science agenda. Naïve realism that ruled for four centuries and held the discovery of natural laws and construction of the most adequate spatial models as an ultimate goal in science, ceded to conventional positivist instrumentalism. The latter is based on belief that the ultimate goal of science is the most economic, precise and complete description of the Nature, and that scientific theories represent inventions, i.e. that arbitrary products of human intelligence, and, therefore, cannot be regarded as anything other than tools.

With this variety of more or less relevant factors, could we accurately assess the effect that has been caused to science development by replacement of inductive methods of scientific cognition by deductive approach? It could be possible based on analysis of those fields of science that have not been affected by the rest of methodological changes. I, for one, find it difficult. However, I would never link the scientific-technological revolution with the transition to hypothetico-deductive methods.

7. *Second Half of the 20th Century*

Development of fundamental science in the second half of the 20th century was marked by the following events. Fundamental physical theories of relativism and quantum mechanics that had been earlier seen as remarkably promising and had greatly contributed in the reform of methodological standards went into a deep crisis. The theory of special relativity has never been able to resolve the controversy of its postulates in the zone of super-light motion, notwithstanding the intensity of the discussions throughout years. The interest to the problem even more increased when a hypothesis was proposed on the existence of tachyons, the elements moving at a super-light speed (1967)¹⁸, and after experimental detection of optical tachyons (1966)¹⁹, as well as the supposed experimental detection of momentary non-local interaction (1972)²⁰. The studies into further development of the general theory of relativity in the direction of the *unified field theory* have never succeeded despite all the tremendous efforts made by Einstein and his successors. The quantum field theory “drowned in mathematics”, and its progressive development phase accomplished in the first half of the century has clearly been followed with regress. Some progress in quantum mechanics brought by the quark theory (1964) and the Standard Model (80’s), whose creation became possible due to the progress in computing technologies (‘t Hooft), was swiftly replaced by a phase of regress. A number of distinguished theoreticians of quantum physics, including the authors of the Standard Model, openly express pessimism about its future development (Dirac, Schwinger, Glashow, Gross, Weinberg, and others). At the March 1996 Symposium on the

conceptual foundations of the QFT at Boston University, Glashow noted that QFT was unacceptable as a final theory²¹.

The “twilight of the scientific age”²² began in the 70’s and since then has been a key problem for philosophy of science. By the end of the 20th century, a radical decline in the rate of development of fundamental science was obvious. The most developed countries have been cutting financing of fundamental science. The Nobel Prize works display a downward tendency in innovativeness. There are other indicators as well that evidence the crisis of fundamental science.

There is a valid opinion nowadays that one of the significant causes of the present crisis in science is the domination of mathematical hypothetico-deductive methods in fundamental theories. One of the serious arguments in favor of this point is provided by the comparative dynamics of development of fundamental and applied science. The latter is much more efficiently utilizing traditional empiric methods, which may be the decisive factor in its continuous progress.

The Table below summarizes the relative balance between the use of inductive and deductive methods in science in various periods of the civilization history. I assess the dynamics of scientific progress during the first of the 20th century as “probably high” (row 6 of the Table) since the rapid progress in fundamental sciences in that time was apparently due to many factors among which the relative balance between the inductive and deductive methods was not a number one factor.

My analysis of the relationship between the rate of scientific knowledge development and the state of methodological fashion has been concentrated on just one aspect. There is a factor of no less, or maybe higher, importance that influences the efficiency of scientific cognition: acceptability threshold for hypothetical elements known to drastically lower the validity level of acquired knowledge. The use of a hypothetical element typically leads to an immediate boom in science, however followed with an inexorable sharp decline in the same field at later stages (if the hypothesis appears invalid) as each failed hypothesis entails a strong setback in

No.	Historic period	Balance between inductive and deductive methods	Resulting dynamics of scientific knowledge development
1.	Antiquity 6 BC – 5 AD	Strong prevalence of inductive methods	Visibly high
2.	Dark Ages 5 th – 16 th cc.	Radical dominance of scholastic-deductive methods	Visibly slow
3.	Renaissance 16-17 th cc.	Prevalence of inductive methods	Visibly high
4.	18 th c.	Imbalance, dominance of inductive methods	Some slowdown
5.	19 th c.	Fair balance between deductive and inductive methods	Visibly high
6.	First half of 20 th c.	Imbalance, dominance of deductive methods	Probably high
7.	Second half of 20 th c.	Severe imbalance, dominance of deductive methods	Dramatic slowdown

the subsequent development of a respective area of knowledge. This seems to be an explanation for the dramatic decline in the development of fundamental science during the second half of the 20th century. The abundance of arbitrary hypothetical elements

used in fundamental theories of the first half of the century had predictably boosted the scientific progress at that time, and appeared to be the cause of the subsequent crisis and the main obstacle in the course of the further development of sciences.

¹ Mill, J. St., *From System of Inductive and Deductive Logic*. 1843 (Russian translation, Moscow, Knizhnoye Delo, 1897, p. 236.

² “There are and can be only two ways of searching into and discovering truth. The one flies from the senses and particulars to the most general axioms, and from these principles, the truth of which it takes for settled and immovable, proceeds to judgment and to the discovery of middle axioms. And this way is now in fashion. The other derives axioms from the senses and particulars, rising by a gradual and unbroken ascent, so that it arrives at the most general axioms last of all. This is the true way, but as yet untried.” F. Bacon *Novum Organum*, I, XIX (Cited from *The Works (Vol. VIII)*; Boston, Taggard and Thompson, 1863.

³ Aristotle, *The Topics*, I, 12 (Rendition based on Russian translation *Sochineniya. T. 2*, Moscow, 1978).

⁴ Descartes, *Rules for the Direction of the Mind*. 1628 (published 1701): RULE III

⁵ Validity or truthfulness of scientific laws is by no means a self-explanatory issue and should be a subject of a special discussion.

⁶ Laudan, L., *Science and Values*. Los Angeles, University of California Press, 1984.

⁷ Roseveare, H. T., *Mercury's Perihelion from Le Verier to Einstein*. Oxford, Clarendon Press, 1982.

⁸ Popper, K. R., *The Logic of Scientific Discovery*. London, 1959.

⁹ Carnap, P., *Meaning and Necessity. A Study in Semantics and Modal Logic*. University of Chicago Press, 1956.

¹⁰ Quine, W. V. *From a Logical Point of View*. Cambridge, Harvard Univ. Press, 1953.

¹¹ Neurath, O. *Le Developpement du Cercle de Vienne et Vavenir de Vempirisme logique*. Paris, 1935.

¹² Hume, D. *An Enquiry Concerning Human Understanding*. 1748. (Cited from: http://www.infidels.org/library/historical/david_hume/human_understanding.html)

¹³ Kuhn, T. *The Structure of Scientific Revolutions*. University of Chicago Press, 1962.

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